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Cyclopedia
of
Civil Engineering

A General Reference Work
ON SURVEYING, RAILROAD ENGINEERING, STRUCTURAL ENGINEERING, ROOFS
AND BRIDGES, MASONRY AND REINFORCED CONCRETE, HIGHWAY
CONSTRUCTION, HYDRAULIC ENGINEERING, IRRIGATION,
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Assisted by a Corps of
CIVIL AND CONSULTING ENGINEERS AND TECHNICAL EXPERTS OF THE
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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost Civil, Structural, Railroad, Hydraulic, and Sanitary Engineers in making these volumes thoroughly representative of the very best and latest practice in every branch of the broad field of Civil Engineering; also for the valuable drawings and data, illustrations, suggestions, criticisms, and other courtesies.

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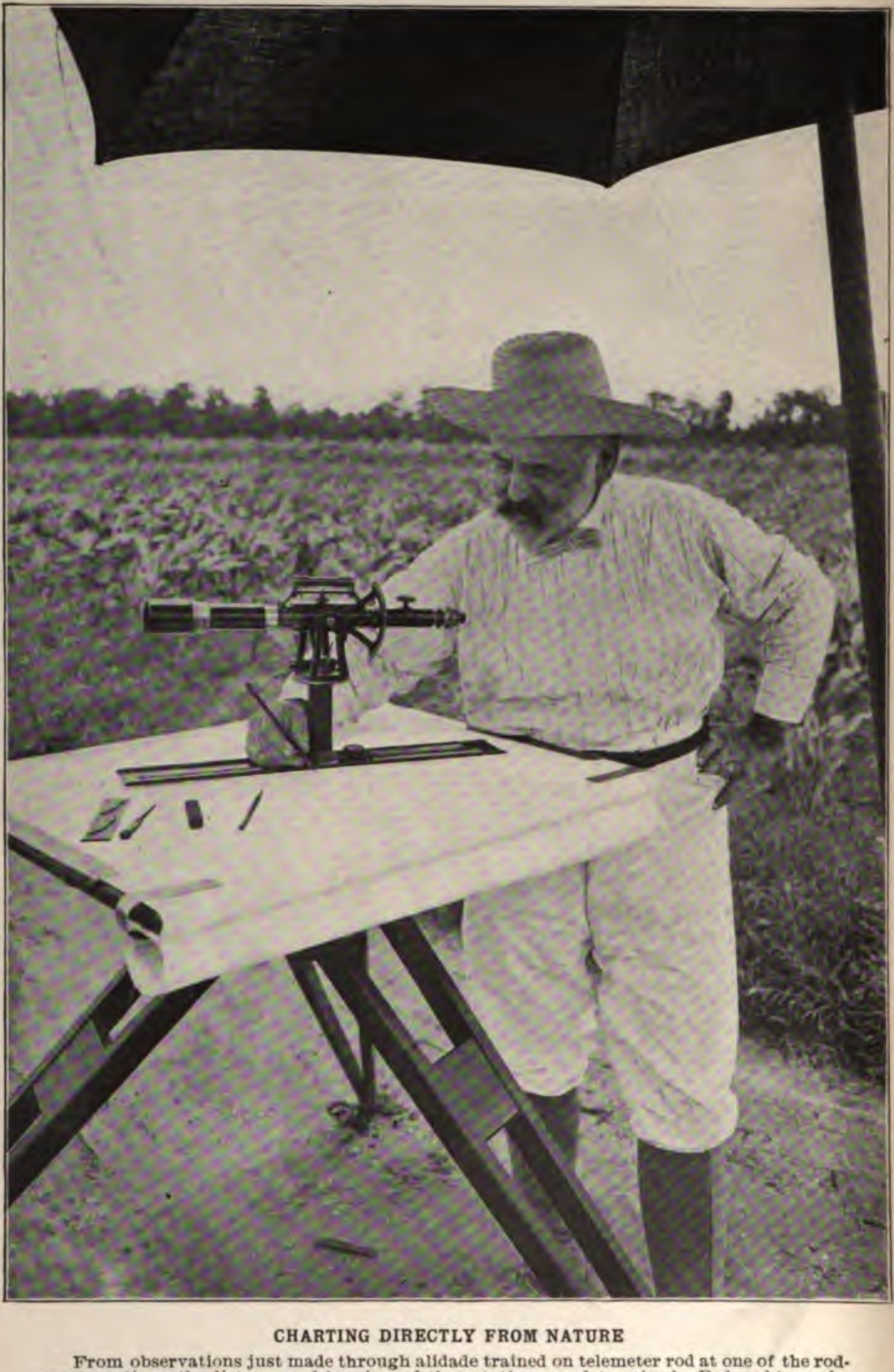

CHARTING DIRECTLY FROM NATURE

From observations just made through alidade trained on telemeter rod at one of the rodmen's stations, the distance and bearing of that station are determined. Reduced to scale, this data corresponds to a line of definite length and direction, which the topographer is here shown drawing directly on the plane-table sheet.

Foreword

THE marvelous developments of the present day in the field of Civil Engineering, as seen in the extension of railroad lines, the improvement of highways and waterways, the increasing application of steel and reinforced concrete to construction work, the development of water power and irrigation projects, etc., have created a distinct necessity for an authoritative work of general reference embodying the results and methods of the latest engineering achievement. The Cyclopedia of Civil Engineering is designed to fill this acknowledged need.

¶ The aim of the publishers has been to create a work which, while adequate to meet all demands of the technically trained expert, will appeal equally to the self-taught practical man, who, as a result of the unavoidable conditions of his environment, may be denied the advantages of training at a resident technical school. The Cyclopedia covers not only the fundamentals that underlie all civil engineering, but their application to all types of engineering problems; and, by placing the reader in direct contact with the experience of teachers fresh from practical work, furnishes him that adjustment to advanced modern needs and conditions which is a necessity even to the technical graduate.

¶ The Cyclopedia of Civil Engineering is a compilation of representative Instruction Books of the American School of Correspondence, and is based upon the method which this school has developed and effectively used for many years in teaching the principles and practice of engineering in its different branches. The success attained by this institution as a factor in the machinery of modern technical education is in itself the best possible guarantee for the present work.

¶ Therefore, while these volumes are a marked innovation in technical literature — representing, as they do, the best ideas and methods of a large number of *different* authors, each an acknowledged authority in his work — they are by no means an experiment, but are in fact based on what long experience has demonstrated to be the best method yet devised for the education of the busy workingman. They have been prepared only after the most careful study of modern needs as developed under conditions of actual practice at engineering headquarters and in the field.

¶ Grateful acknowledgment is due the corps of authors and collaborators — engineers of wide practical experience, and teachers of well-recognized ability — without whose co-operation this work would have been impossible.

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SURVEYING PARTY OF U. S. ARMY ENGINEER CORPS AT WORK IN THE FIELD

PLANE SURVEYING.

PART I.

Surveying is the art of determining, from measurements made upon the ground, the relative positions of points or lines upon the surface of the earth and of keeping records of such measurements in a clear and intelligent manner so that a picture (called plat) may be made of the lines or areas included in the survey. The records should be systematically arranged so that any person with a knowledge of surveying can use the notes intelligently. The field operations consist essentially of locating points, measuring lines and angles, measuring areas and laying out and dividing up areas. It is apparent that Arithmetic and Geometry are essential to the successful application of the principles of Surveying.

The subject may be divided into two parts: Plane Surveying and Geodetic Surveying.

In **Plane** Surveying, the portion of the earth included in the survey is regarded as a horizontal plane; in other words, the curvature of the earth's surface is neglected. In the ordinary operations of land surveying this assumption will not cause appreciable error as the lines and areas dealt with are of a limited extent.

As **Geodetic** Surveying, on the other hand, deals with extensive lines and vast areas, the effect of the curvature of the earth's surface must be taken into consideration.

All of the operations of surveying must proceed from the direct to the indirect. That is to say, we must first measure directly certain quantities upon the ground and from these calculate certain other quantities that cannot be measured directly. It is, therefore, apparent that all field measurements must be made with the utmost care, consistent with the nature of the problem involved, and that habitual inaccuracy and slovenly methods of keeping field notes must be avoided. Full details accurately measured and carefully and systematically recorded should be the aim of every engineer who would ultimately achieve success.

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Measurement of lines. Probably the most elementary problem that presents itself is to measure the horizontal distance between two points without the use of instruments.

This can best be done by pacing, provided both points are accessible. In order to make this method of measurement efficient, it is necessary to determine as accurately as possible the length of one's pace. To do this, lay off upon firm, level ground by any convenient method, a line from 50 to 100 feet in length. Pass over this line from end to end, back and forth, keeping careful account of the number of steps taken each time the distance is covered. The total distance traversed, divided by the total number of steps will give the average length of one's pace. In thus ascertaining the length of the pace do not attempt to cover three feet at every step. It is better to adopt a natural, swinging gait.

Having thus determined the length of one's pace, the distance between two points may be measured approximately by walking in a straight line from point to point and counting the number of steps. This number multiplied by the length of step will give the length of line required. If the intervening space between the points cannot be traversed, as for instance when the two points are on opposite sides of a stream, the width of the stream may be ascertained approximately by stationing an observer on each side and noting the time elapsing between the flash of a pistol and the sound of the report. This interval, in seconds, multiplied by 1,090 (velocity of sound in feet per second) will give the distance in feet. Proper allowance must be made for direction and intensity of wind and therefore measurements of this kind had best be made upon a quiet day.

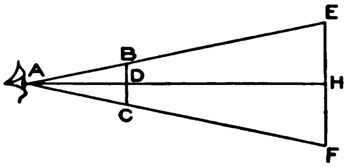


Fig. 1.

Another elementary problem frequently met with is as follows: Required to determine the altitude of an object such as a house or a tree, without the use of an instrument.

To solve this problem, take an ordinary lead pencil and hold it in a vertical position about two feet from the eye, the observer being far enough from the object for the visual angle intercepted by the pencil to just cover the object from top to bottom. The observer then paces the distance from his position to the object. The height of the object is determined as follows :

Let A, Fig. 1, represent the position of the observer's eye; BC the pencil held at the distance AD from the eye; EF the object whose height is to be ascertained. AH is the distance from the observer to the object and is to be paced. Then from similar triangles we have

$$BC : EF : : AD : AH, \text{ or } EF = \frac{BC \times AH}{AD}$$

For example, suppose the pencil is seven inches long and is held at a distance of two feet from the eye; the distance from the observer to the object being 85 feet. Then from the formula

$$EF = \frac{\frac{7}{12} \times 85}{2} = 24.8 \text{ feet nearly.}$$

In this, as in other problems, all quantities should be reduced to the same units.

The examples just given must be understood as illustrations merely and the student should avoid slipshod methods ; understanding that his best efforts will be needed in all surveying problems, and that the best is none too good.

SURVEYING WITH INSTRUMENTS.

Gunter's Chain, so called from the inventor, is well adapted to all classes of problems involving the calculation of areas from lines measured in the field. For many years this chain has been the English linear unit for all land measurements. It should be made of steel; it is 66 feet or 4 rods in length and has 100 links, each 7.92 inches. The handles are fitted with swivels to prevent the chain from kinking, and at every tenth link from either end is attached a brass tag with 1, 2, 3 or 4 prongs to assist in measuring. Thus the tag of four prongs indicates 40 links from one end, (See Fig. 2) but it represents 60 links from the other end; therefore care must be exercised in measuring, or distances may be measured from the wrong end of the chain. The 50-link mark is round in form so that it may be easily distinguished from the other tags. Since the parts are called links, the length is expressed in chains and links; it is written thus: 15 chains and 82 links is 15.82 chains.

It is true that this chain is rapidly going out of use, yet one should be thoroughly acquainted with it, because many of the land records in this country are based upon it. In computing areas, the chain has the advantage that square chains are easily reduced to acres by simply moving the decimal point one place to the left; for example, a chain is 66 feet; the square would be $66 \times 66 = 4356$ square feet, which is $\frac{1}{10}$ of an acre. A rectangular lot having two sides of 6.32 and 2.15 chains respectively = 13.5880 square chains or 1.3588 acres.

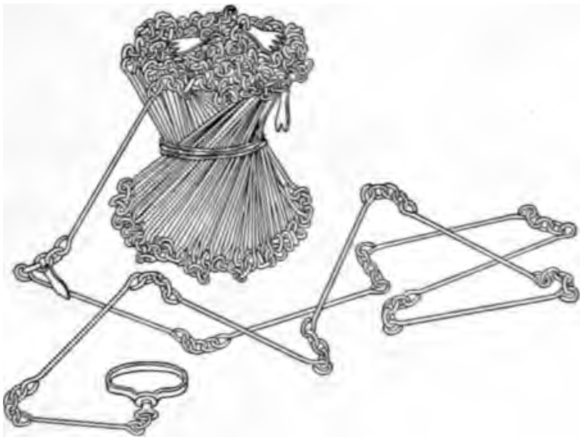


Fig. 2.

GUNTER'S OR LAND MEASURE.

7.92 inches	1 link
100 links or 66 feet or 4 rods	1 chain
10 square chains or 4 roods	1 acre = 43560 square feet
640 acres	1 square mile

A two-rod or half chain is sometimes used instead of the full Gunter's chain. Its only advantage is in the convenience of handling a shorter chain when working over uneven ground. Formerly the engineer's chain was almost universally employed in making surveys for surface canals, sewers, water-works systems, etc. It differs from the Gunter's chain in that is 100 feet in length and contains 100 links, each of which is, therefore, 1 foot long.

The unit of linear measure in the United States is the foot.

In measuring lines, a chain 100 feet long, divided into 100 links, is now in use. Distances are recorded in feet; decimals of a foot being used when possible. In cities where accurate and precise measurements are necessary, various kinds of tapes are used having the foot divided decimally.

It has been decided both by custom and law that the length of the boundary lines of a field is not the actual distance on the surface of the ground, but is the projection of that distance on a horizontal plane. The area of a field is not the exposed superficial surface, but as above stated, the projection of that surface on a horizontal plane. *For this reason, in all land surveying,* horizontal distances are to be measured and from these the areas computed.

The Gunter's chain, as well as the engineer's chain, is a very inaccurate device for measuring distances and areas unless special precautions are taken to counteract the errors to which it is liable. Some of these errors are cumulative and some compensating, and in what follows no attempt will be made to classify them. Some of the causes of errors will be pointed out and the surveyor should do all in his power to eliminate them.

The chain will sag between supports and thus the distance measured will be too short. This is sometimes allowed for by making the chain a given amount longer than the standard. Again, the chain may be standard under a certain pull and temperature, and for very precise work a spring balance is attached to one end of the chain to register the pull. A thermometer also is provided but is of little value from the fact that the temperature of the chain may vary considerably from that of the atmosphere. Still further, the length of the chain is likely to be increased from the wear of the links and connections. Each link with its connection has six wearing surfaces so that if each surface is worn away but $\frac{1}{100}$ inch the chain will elongate 6 inches. The rings and loops at the end of the links are frequently stretched out of the true form, thus elongating the chain; or the links may become bent, thus shortening the chain. In pulling the chain over the ground the links and rings have a tendency to collect weeds, mud, etc., and thus shorten the chain. In cold weather, ice and snow may collect in the joints with the same result. In using the chain, the links and rings kink and twist, and a sudden jerk may break the chain. For these reasons the chain is not at present used as much as formerly.

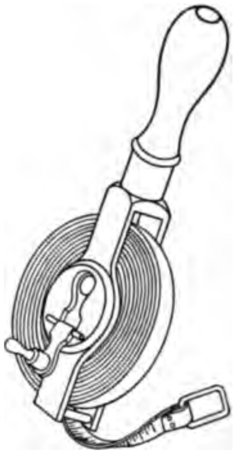
The Tape. Tapes are made of various materials and are known as linen, metallic and steel.

Linen tapes, from the nature of the material, are likely to twist and tangle and when wet are easily stretched; for these reasons they do not long retain their standard length. They are used only in the roughest kind of work. Metallic tapes have a linen body with threads of copper or brass running throughout their length. These metallic threads prevent twisting and tangling and in a general way assist in preserving the standard length of the tape. They are better than linen tapes but not suitable for "good" work.

Steel tapes are of two kinds, "ribbon" and "band." Ribbon tapes are made of thin steel about $\frac{3}{8}$ inch wide. They are usually made in lengths of 50 or 100 feet. They are divided into feet, tenths and hundredths of a foot, the divisions being etched upon the tape. The other side of the tape is sometimes divided into rods and links to adapt it to land surveying, and it is either wound up into a leather case or upon a reel.

Ribbon tapes are generally used when considerable accuracy in measurements is required, such as laying out foundations for buildings, bridge piers, measuring up sewer lines, etc. From the nature of their construction, they will not stand much wear and tear, and are therefore not adapted to the rough usuage of general field work. If carried in the case or reel, on account of the sharp bend at the center, the tape will soon break off at that point. After use in the field, the tape should be carefully wiped off and oiled if necessary, as the rust will obliterate the graduations and make it difficult to read. In using the ribbon tape in the field, care must be exercised to prevent twisting and kinking or catching under sticks or stones, as a slight jerk will break it.

The band tape is best adapted to general field work and to rough usage. It is made of heavy steel about $\frac{5}{16}$ of an inch wide and 100 feet long, divided into feet; usually the first and last foot are divided into tenths. The one-foot divisions may be marked by rivets, although the rivets tend to weaken the tape. They are sometimes marked by solder, which is notched at the proper point and stamped with the number. They are usually fitted with light, detachable handles for use in the field, but these are easily displaced or often lost in dragging the tape over stones or through grass. It is better to fit the tape with leather handles large enough to easily go over the hand. After use, the band tape should be gathered up in loops about three feet long and tied in the middle forming a figure eight. If it is desirable to wind the tape upon a reel, there are at present upon the market, several styles of reels, stiff in construction and convenient to carry.


The Tape.

The tape, like the chain, is likely to change in length due to changes of temperatures, and unless the proper pull is applied to the ends it will measure short of the standard. Altogether it is more accurate than the chain and of late years has largely replaced it for all kinds of field work. Indeed, with proper precautions, it has been found possible to obtain nearly as accurate results as with the most elaborate apparatus designed for measuring lines.

Since the methods of using the chain in the field are the same as for using the tape it will be sufficient to explain the methods of using the latter.

In connection with the tape there should be provided a set of eleven marking pins from 15 to 18 inches in length. To each pin should be attached a piece of red flannel to prevent its being overlooked in the grass. There should also be provided two rods (called flags), from 6 to 8 feet in length divided into foot lengths and painted alternately red and white. These rods are sometimes constructed of straight white pine, but $\frac{3}{4}$-inch gas pipe fitted with a steel shoe is better. It is desirable also, to provide a plumb-bob and string, and a hatchet.

Use of the Tape or Chain. For measuring a line with the tape, two men are required; a "leader" and "follower," or *head* and *rear* tapemen. The first step is to set one of the flags at the far end of the line to be measured, or if the line is too long, only as far ahead as can be distinctly seen. It is best to mark the beginning of a line with a stake driven as closely to the ground as circumstances will permit. The tape is then unrolled or unfolded in the direction of the line, the 100-foot mark going ahead. The leader takes the pins and the forward end of the tape and with a flag walks off in the direction of the forward end of the line, dragging the tape after him. When nearly one hundred feet away, the follower cries "down" and the leader faces the follower holding the flag vertically to be signalled into line by the follower. The tape is then stretched and straightened and a pin stuck vertically into the ground exactly at the 100-foot mark. The leader then picks up his end of the tape and starts off as before, the process being repeated each time, except that the follower must be particular to pick up each pin that is left in the ground by the leader.

If the line is more than eleven tapes in length, after the leader has stuck his last pin he cries "pins" and the follower delivers to him the ten pins that he has picked up. If the line to be measured is very long, some method should be adopted for keeping count of the number of times the pins have been exchanged. If the line ends with less than the length of a tape, the leader pulls out the tape to its full length, not sticking a pin, however, and then walks back and notes the distance from the last pin to the end of the line. This distance added to the number of pins held by the follower, including the last one stuck, will give the distance from the point at which the pins were exchanged. For instance, if the follower has six pins and the end of the line is 65 feet from the last pin, the entire distance from the point of exchange of pins is 665 feet. It must be remembered that each exchange of pins counts for 10 tape lengths or 1,000 feet.

Chaining on Slopes. One of the most important uses of the chain is to measure accurately distances where the surface of the land is uneven or of a sloping nature. In measuring up or down a slope, one end of the tape is raised until the top is as nearly as possible in a horizontal plane. If the slope is too steep to permit of one end of a full tape being raised enough to bring the tape horizontal, the tape is "broken," that is to say, only a part of the tape is used at each measurement. To do this the tape should be stretched to its full length, the leader returning to such a point upon the tape that the portion between himself and the follower may be properly leveled. A measurement is made with this portion, the operation being repeated with the next section of tape and so on until the entire tape has been used. Care should be taken not to confuse the pins. The high end of the tape may be transferred in any one of several ways, depending upon the degree of accuracy required. For great accuracy, a plumb-bob should be used but it should not be dropped and the pin placed in the hole made. It should be placed about where the bob will drop and the grass should be tramped down and the ground smoothed. The bob should then be lowered carefully until it almost touches the ground and allowed to come to rest. Then lower it until it reaches the ground when the pin should be stuck in the ground slantwise across the line exactly at the point of the bob. If less accuracy is permissible, it may be sufficient to drop the pin, ring end down and note where it strikes the ground, or a pebble may be dropped in the same way. In measuring uphill, the follower must hold the bob directly over the pin in the ground while he aligns the leader and sees that he sticks the pin while the bob is directly over the point in the ground. It is much easier to measure down than up hill so that when close measurements are required on slopes, the measurement should, if possible, be made down hill. Even under the most favorable conditions measuring lines with a tape is a most difficult operation for experts, and beginners cannot expect to attain efficiency except by constant practice and careful attention to every detail that will tend to eliminate error. For the method of chaining up and down hill, see Fig. 3.

Let it be required to find the distance A M, at which points two hubs have been established. Let A B C D E F, etc., be the points of the successive chaining and *a b c d*, etc., the horizontal planes. Starting from the point A; suppose the surface between A and B to be of no great difference in elevation, therefore, the full length of the chain can be used between these two points. The head chainman goes to the point B, and holds the head end of the chain on the ground, while the rear chainman holds the zero end at A and with aid of the plumb-bob "plumbs down," thus chaining the distance horizontal. This distance measured, the head chainman establishes a peg in the ground and calls out the distance "One hundred" or station one, then goes to C, which must be approximately low enough to allow the rear chainman to conveniently plumb down to B. In this case the slope of the hill is greater than that between A and B, thus the impracticability of using the full length of the chain is apparent. This distance, therefore, is taken at a fractional part of the chain, as before stated, called "breaking the chain." The distances at such breaks should always be taken at an even number of feet whenever possible and at distances that are easily remembered, as 10, 20, 25, 50 feet, etc. The leader in every instance calls out the distance of such "breaks" and the rear chainman goes to the next peg and holds off the number of feet previously called out. Now as the distance A B is 100 feet and the distance B C 40 feet, the head chainman at C calls out "1 plus 40," meaning 140 feet from A. He next goes to D and the rear chainman calls out the distance measured "1 plus 40" and holds off 40 feet at *b*, and plumbs down to C. In this case the leader also plumbs down from *c* to D. This method is continued

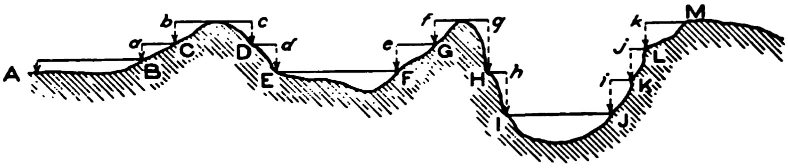


Fig. 3.

until M is reached, using the system of 1, 2, 3, 4, etc., plus the fractional measured distance, instead of using the whole number, as 125, 225, etc. The rear chainman should gather the pins after a new point has been established. As already stated the chaining can be checked by counting the pins picked up. Always allow the last pin to remain in the ground until absolutely certain it is no longer desired and can be of no further service. It is important that the distances should be checked by both chainmen as it may prevent serious mistakes, and in some cases prevent rechaining the entire distance. Distances in places where angles are taken are sometimes checked in the office by Trigonometry.

A few hints in regard to the use of the tape may not come amiss.

Always measure to and from the same side of a pin.

Hold the end of the tape as near the ground as possible.

Before sticking the pin, be sure there are no kinks in the tape and that the tape is not deflected to one side by grass, sticks or stones.

Never straighten the tape with a jerk; raise it clear of the ground and straighten and stretch with a steady pull and lower steadily into place.

The tape man should never brace himself against a pin; he should assume a position of stable equilibrium, preferably with one hand upon the ground.

In passing over uneven ground, every reasonable effort should be made to hold the tape level. Too much time should not be spent in attempting to hold the end of the tape exactly over the point in the ground when the difference of level of the ends of the tape is sufficient to neutralize what would otherwise be considered an accurate measurement.

In passing over rough ground the tape should be carried free from the ground, thus saving it unnecessary wear. The length of the tape is likely to vary from time to time, from changes in temperature, from constant stretching and from accident in the field. For this reason the surveyor should compare frequently the lengths of his tapes with that of a standard. The length of the standard tape may sometimes be conveniently laid off upon the floor of a building, or two monuments may be set in the ground, the proper distance between them being measured either by a standardized tape or by means of wooden rods. Having found the error in the length of the tape the necessary corrections can then be made. If a line has been measured upon the ground, and it is afterwards found that the length of the tape is in error, the true length of the line may be found from the following proportion: the true length of the tape is to the length of the standard tape, as the true length of the line is to the length of the line as measured.

Suppose a line as measured, is found to be 625 feet in length and it is afterwards found that the tape is too long, by six inches.

Then we have: $100.5 : 100 :: x : 625$

from which $x =$ true length of line $= 628\frac{1}{8}$ feet.

EXAMPLES FOR PRACTICE.

1. A line as measured with a certain tape is 580 feet in length. It is afterward found that the tape is $\frac{3}{10}$ of a foot too short. Determine the true length of the line. Ans. 578.26 feet.

2. A line is known to be 840 feet in length, but when measured with a certain tape is found to be $842\frac{1}{4}$ feet in length. Determine the true length of the tape.

Ans. 99.7 feet.

3. A certain field was measured with a Gunter's chain and found to contain 625 acres. It was afterwards found that the chain was $\frac{1}{4}$ foot too long. Determine the true area of the field.

Ans. 629.74 acres.

If an area has been measured with a certain tape that is afterwards found to be in error, the corrected area may be found by the following proportion: The square of the true length of the tape is to the square of the length of the standard tape as the true area is to the measured area.

Examples will now be given illustrating the use of the chain or tape, in the field.

1. *To erect a perpendicular at a given point in a line.* Let AB Fig. 4 be the given line and C the point in the line at which it is desired to erect a perpendicular. Since a triangle formed of the sides 3, 4 and 5 (or any multiple of these) will contain a right triangle, take parts of the chain or tape representing these distances or multiples and have the angle included between the shorter sides at C. Therefore, fasten one end of the tape or chain at E, 30 links or feet from C and the 90th link or foot at C. Then with the 50-foot mark in one hand, walk away from BC until both of the segments DE and DC are taut. Stick a pin or stake at D and DC will be the perpendicular required. If the perpendicular should be longer than can be laid out with the tape or chain, lay out CD as described and align a "flag" from C to D produced.

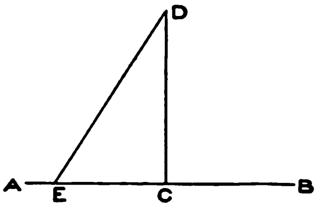


Fig. 4.

2. *To let fall a perpendicular to a given line from a given point outside the line.* (a) When the point is accessible:

Let AB Fig. 5 be a given line and C a point. From C as a center, with any convenient length of tape or chain as a radius, describe the arc DE, cutting the given line at points D and E. Stick pins at D and E and measure the distance. Bisect this distance at F; then CF will be the perpendicular required. If the line AB is too far from C to be reached with the chain or tape, it will be necessary to range out a line conveniently near to C which shall be parallel to AB. To do this erect at any convenient point on AB, as at N, Fig. 6, the perpendicular, and prolong it as far as necessary, as R. At R, erect RS perpendicular to RN. Then the perpendicular let fall from C upon RS and prolonged to AB will be perpendicular to AB.

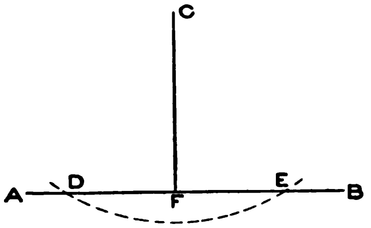


Fig. 5.

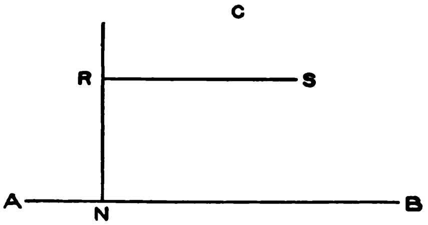


Fig. 6.

(b) When the point is inaccessible: Let AB, Fig. 7, be the given line and C the inaccessible point from which it is desired to drop the perpendicular to the line AB. At any convenient point F in AB erect the perpendicular FD and extend FD to E, so that FE=FD. Locate the point B so that B, D and C will be in the same straight line. Sight from E to C and find the point H in which this visual line crosses AB. Next find the point G at the intersections of DH and BE prolonged. Sight from G to C and the point M in which this visual line crosses AB will be the point required and the distance MG will equal MC. MC will be the perpendicular to AB at M.

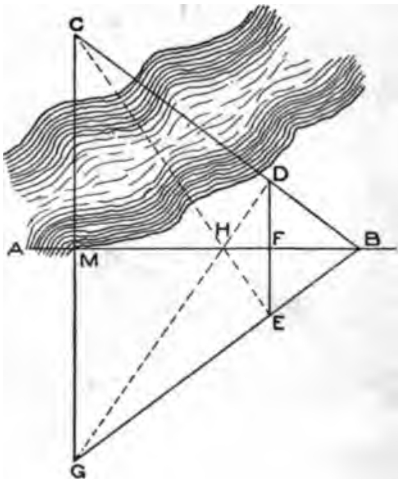


Fig. 7.

3. *Through a given point to run a line that shall be parallel to the given line.* The given point and given line being accessible: Let C, Fig. 8, be the given point and AB the given line.

From point C let fall CD perpendicular to AB. At C erect CF perpendicular to CD; then EF will be the parallel required.

4. *To prolong a line beyond an obstacle.* Let AB, Fig. 9, be the given line which is intercepted by a tree, house or other obstacle. It is required to locate the line CD which will be in the direction of AB produced. At B erect BE perpendicular to AB of sufficient length to clear the obstacle and at E erect EF perpendicular to EB prolonging EF beyond the obstacle. At F and C erect perpendiculars to EF and CF making CF equal in length to BE, then CD will be the line required and the distance from A to D will equal AB plus EF plus CD.

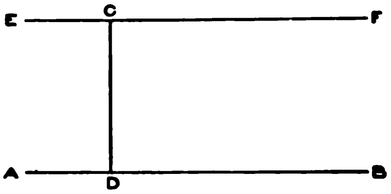


Fig. 8.

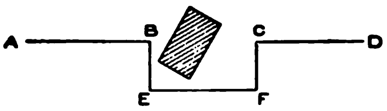


Fig. 9.

5. *When both ends of a line are accessible, but the line cannot be measured directly, on account of obstacles.*

At each end of the line erect perpendiculars of equal length sufficient to clear the obstacles, and measure the length of the line between the extremities of these perpendiculars.

6. *When both ends of a line are accessible, but neither can be seen from the other, thus preventing direct alignment.*

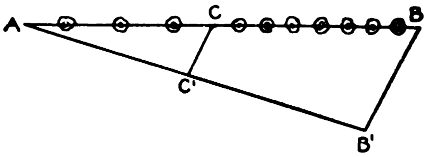


Fig. 10.

Such a case occurs when it is desired to run a line across a wooded field, the trees and underbrush preventing the alignment of the intermediate stations. Let AB Fig. 10 be the line whose length is desired. From A run a line AB′ (called a random line) in any convenient direction and continue it till the point B can be seen from B′. At B′ erect the perpendicular BB′ to AB′ and measure BB′. Then from the right-angled triangle ABB′ we will have

$$AB=\sqrt{\overline{AB'}^2+\overline{BB'}^2}$$

The distance from A to any intermediate station as C can be found by measuring the length of the perpendicular CC′ to AB′ From similar triangles we have

$$AC : CC' :: AB : BB'$$

$$\text{or } AC = \frac{CC' \times AB}{BB'}$$

7. *To locate points in a line over a hill, both ends of which are visible from points near the summit.*

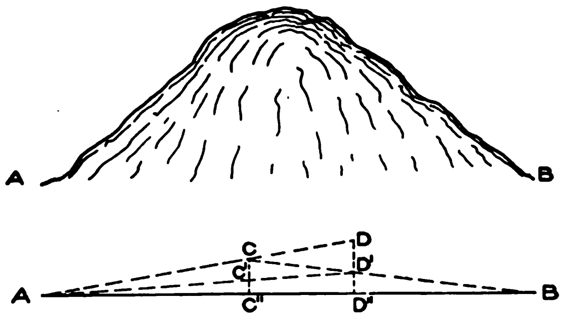


Fig. 11.

Set a flag at each of the points A and B Fig. 11. One man then goes to D, as closely in line with A and B as can be estimated. He then signals a man at C in line with A. C then signals D to D′ in line with B. D′ signals C to C′ in line with A and so on alternately until the points C″ and D″ are reached in line with A and B.

If the points A and B cannot be seen from the top of the hill, run a random line over the hill as described in problem 6 and offset to the true line.

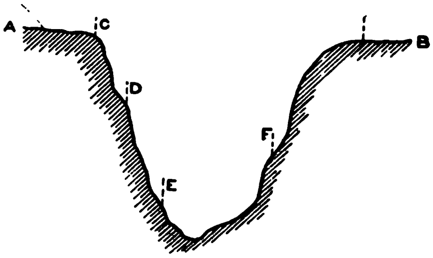


Fig. 12.

8. *To locate points in a line across a wide, deep valley, the extremities of the line being visible from each other.*

Fix a point C, Fig. 12, on the edge of the slope in line with A and B. Then holding a plumb-line at C and sighting across to B the intermediate points D. E. F and C can be put into line.

1. **The Field Work of Measuring Areas.** *Let us consider the triangular field ABC, Fig. 13.* Beginning at any convenient corner as A, measure from A to B, then from B to C, and finally from C to the point of beginning. Should a stream cut across the field as shown, measurements should be made from the corners to the points where stream crosses the boundary lines. Should it be found impossible to measure the sides of the field directly, owing to zigzag fences or other obstacles, offset parallel lines as in the figure and measure the length between such parallels.

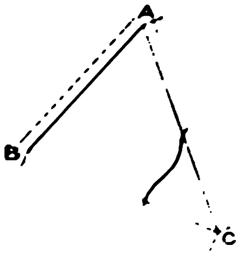


Fig. 13

The area of the figure may be found from the following rule: From one-half the sum of the three sides, subtract each side separately. Multiply together the half sum and the three remainders and extract the square root of the product. The rule is explained in Art. 198 of Elementary Algebra and Mensuration.

If the lengths of the sides are given in chains, the area will be given in square chains. If the lengths of the sides are in feet, the result will be in square feet.

2. *To survey a four-sided field with the tape or chain.* Measure around the field in the same way as before, but in addition, it will be necessary to measure a tie-line between two opposite corners, thus dividing the figure into two triangles, the sum of whose areas will give the area of the entire figure. Such a tie line is shown in Fig. 14 by the dotted line DB. If neither of the diagonals DB nor AC can be conveniently measured, measure the short tie line LS for instance, and the distances CS and CL. Then in the triangle LCS the three sides are given, from which to find the angle LCS. Having this angle, we can calculate the length of DB and therefore the area of the two triangles composing the field.

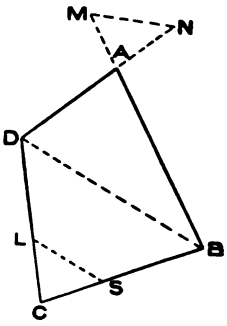


Fig. 14.

If it is not convenient to measure the tie-lines inside the field,

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two adjacent sides as BA and DA can be prolonged to M and N forming the tie-line MN. It will usually be found more convenient to lay off CS equal to CL, thus forming an isosceles triangle.

3. *To survey a five-sided field with the tape or chain.* In this case two diagonals as EB and BD, Fig. 15, or two tie-lines as es and mn must be measured in addition to the lengths of the sides. Whatever the number of sides, a sufficient number of diagonals or tie-lines should be measured to divide the area into triangles from which the area of the entire field may be calculated.

If N represents the number of sides of a field, there will be required N–3 diagonals or tie-lines, forming N–2 triangles.

To simplify calculations when tie-lines are used in place of the long diagonals, the following method may be adopted:

Measure off Am any fractional portion of AE, and An the same fractional portion of AB and measure mn. Then mn will be to EB as Am is to AE or as An is to AB. Suppose for example that Am is $\frac{1}{10}$ of AE and An is $\frac{1}{10}$ of AB. Therefore EB is 10 times the length of mn.

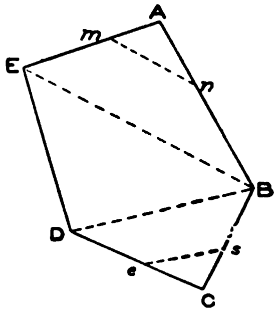

Fig. 15.

EXAMPLES FOR PRACTICE.

1. Given the three sides of a field as 5.25, 6.50 and 4.60 chains. Find the area of the field in acres, and square rods.

Ans. 1 acre, 31.52 square rods.

2. Given CB=3.65 chains, CD=2.85 chains, Cs=Ce=0.50 chains and es=0.65 chains.* Calculate the area of the triangle BCD.

Ans. 5.14 square chains area.

Off-sets and Tie-lines. To find the area of a field which is bounded in part by a stream, it is necessary to use off-sets, as follows: Measure the sides of the field in the usual manner and for the irregular boundary run a straight line, as ED, Fig. 16, and calculate the area of the field included between these boundary lines. To this area must be added the area included between the line ED and the irregular boundary.

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*Note: In all problems involving the measurement of land, the chain referred to is the Gunter's chain of 66 feet, unless otherwise noted.

To find this area, at points along ED, erect perpendiculars to the irregular shore line at such distances that the lines 1′ 2′, 2′ 3′ etc., may be considered straight. The desired area will evidently equal the sum of the areas of the trapezoids thus formed. The distance from E to any point 1, 2 or 3 on ED is called the *abscissa* of that point and the perpendicular distances from ED to 1′ 2′ 3′ etc., are called the *ordinates* of the point.

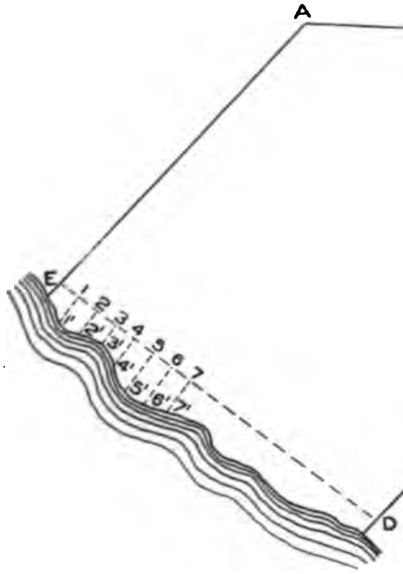


Fig. 16.

Instead of summing the trapezoid as above, the desired area may be found by the following rule: Multiply the difference between each ordinate and the second succeeding one by the abscissa of the intervening ordinate. Multiply also the sum of the last two ordinates by the last abscissa; one-half of the algebraic sum of these several products will be the area required.

To find the area of an inaccessible swamp, a lake or other area, run a series of straight lines entirely enclosing the given area, and since the diagonals cannot be measured, measure tie-lines either inside or outside of the area. As already stated, calculate the area included between the straight boundary lines and from this area substract the area included between off-sets let fall from points upon these boundary lines. Reference to Fig. 17 will make the method of procedure plain. Surround the inaccessible area by straight lines, AB, BC, CD, etc., and calculate the enclosed area. At proper intervals along these straight lines, erect and measure perpendiculars extending to the edge of the inaccessible area. Compute the area between these perpendiculars by the rule on page 20 and for the required area, subtract it from the area previously found. Since the long diagonals are not accessible, measure the area by measuring the interior tie-lines; remembering that the required number of tie-lines will be less by 3 than the number of sides enclosing the area.

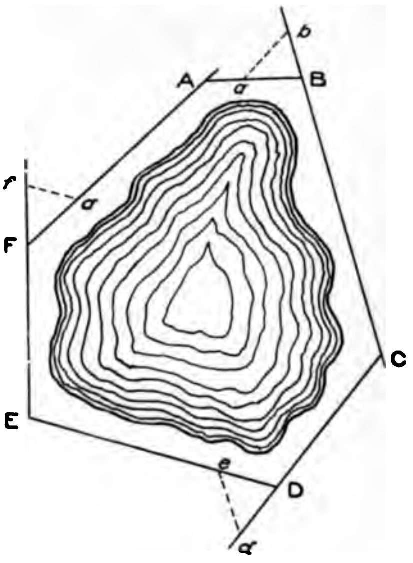


Fig. 17.

Example. Given the distances measured along the straight line AB (Fig. 18) with the corresponding off-sets measured to the broken line ACDE. It is required to compute the area between A B and the broken line ACDE.

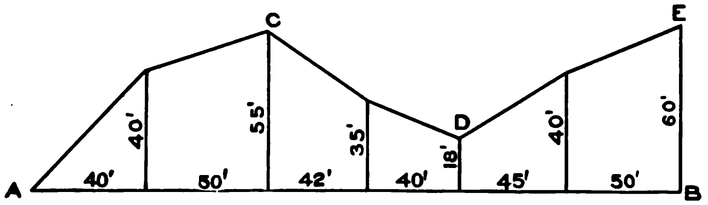


Fig. 18.

Difference of 1st and 3rd ordinates = 0′ − 55′ = − 55′ etc.
" " 2nd " 4th " = 40′ − 35′ = + 5′
" " 3rd " 5th " = 55′ − 18′ = + 37′
" " 4th " 6th " = 35′ − 40′ = − 5′
" " 5th " 7th " = 18′ − 60′ = − 42′
Sum of last two ordinates = 40′ + 60′ = 100′

Abscissa of intermediate ordinates between 1st and 3rd= $40' \times -55' = -2200$
" " " " " 2nd " 4th= $90' \times +5' = 450$
" " " " " 3rd " 5th= $132' \times +37' = 4884$
" " " " " 4th " 6th= $172' \times -5' = -800$
" " " " " 5th " 7th= $217' \times -42' = -9114$
" " last ordinate $= 267' \times 100' = 26700$

One-half the algebraic sum of the products as given above will give the required area.

$$\text{Area} = \frac{32034 - 12174}{2} = 9930 \text{ square feet.}$$

EXAMPLE FOR PRACTICE.

1. Given the distances measured along the straight line AB Fig. A with the corresponding off-sets measured to the broken line ACDEFB, to find the area between AB and the broken line ACDEFB. Check the result by calculating the areas of the trapezoids and triangles of the figure. Ans. 11,875 square feet.

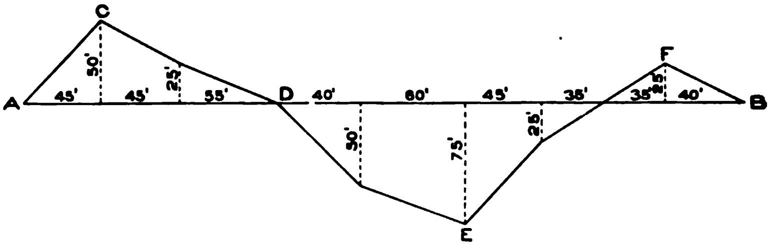
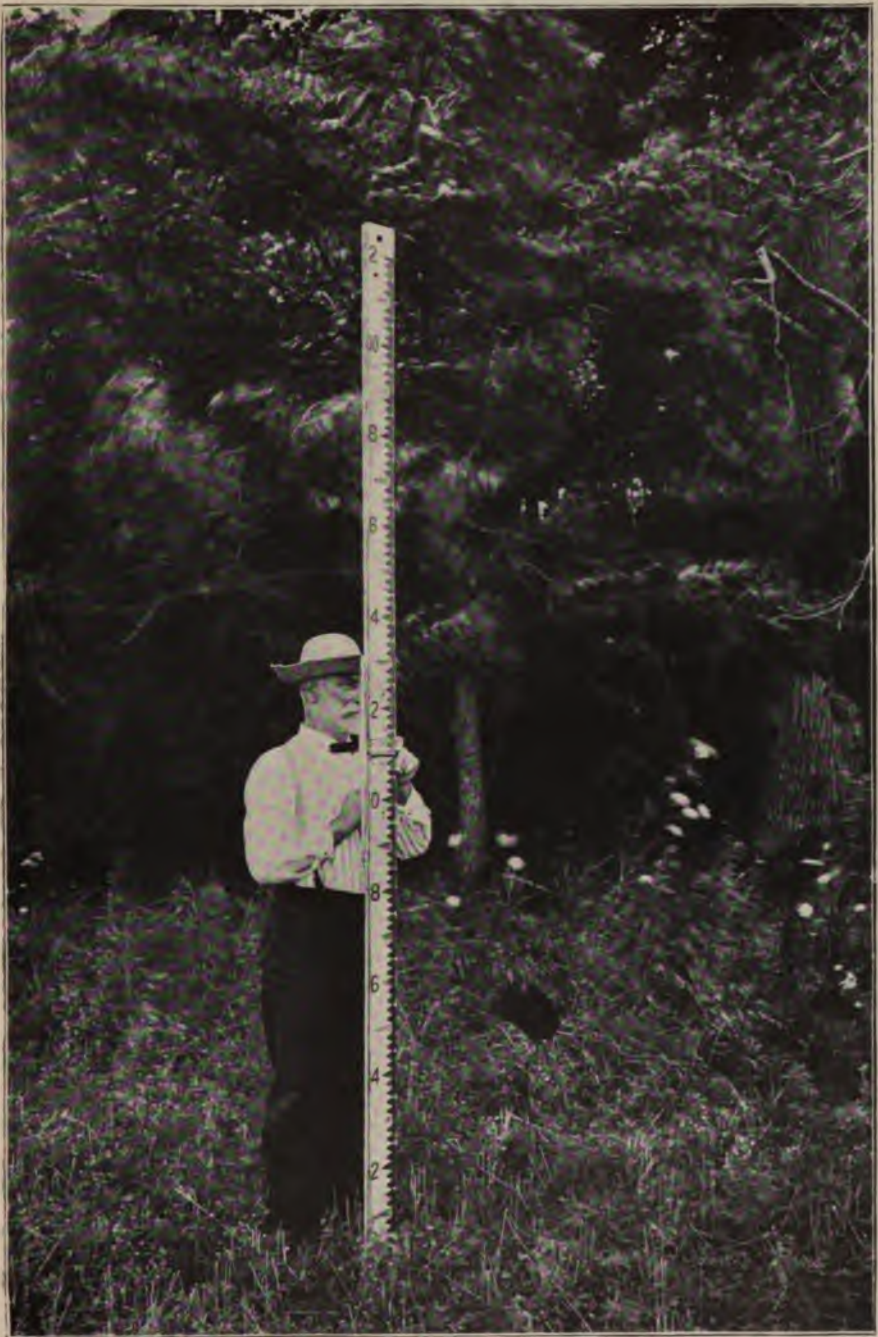


Fig. A.

Keeping the Field Notes. In keeping field notes, clearness and fullness should be constantly kept in mind. As field notes often pass into the hands of a second party, they should admit of but one interpretation to a person at all acquainted with the nature of the work. Extra time spent in the field in acquiring data will avoid confusion and vexatious delays when the notes are worked up in the office. Avoid the habit of keeping notes upon scraps of paper or in vest-pocket note books. Provide note books especially adapted to the keeping of field records and number and index them so that the contents may be understood at a glance. Remember that sketches made upon the ground aid materially in interpreting field notes that otherwise might be unintelligible.

There are three principal methods of keeping field notes; first, by sketches alone; second, by notes alone; and third by full notes



RODMAN OF A PLANE-TABLE PARTY AT A STATION

The divisions on the telemeter rod, read between the cross-hairs of the surveyor's telescope, indicate the distance of the rod from the instrument.

supplemented by sketches. The third method is without doubt the best, but examples of the others will be given. For keeping the notes of the chain survey there should be provided what is known as a field book, a pencil (preferably 4H), rubber eraser and and a short rule for drawing straight lines.

First, by Sketches Alone. Either page of the note book may be used for sketching but it will be more convenient to use the right-hand page, as it is ruled into squares, thus permitting sketching to scale. Always sketch in the direction of the survey, beginning at the bottom of the page and making the center line of the page correspond approximately with the North and South lines.

Second, by Notes Alone. Use the left-hand page of the note book beginning at the bottom as before. Do not crowd the notes, and if necessary use two or more pages. See Fig. 19.

Fig. 19 shows the method of keeping the notes of the survey shown in Fig. 20.

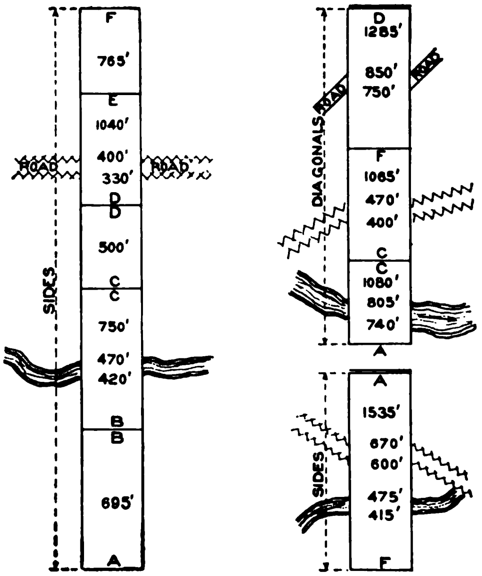


Fig. 19.

Third, by Notes and Sketches. It is apparent that in this method both the first and second methods are embodied in the notes.

THE VERNIER.

The vernier is an auxiliary scale for measuring with greater precision the spaces into which the principal scale is divided. The smallest reading of the vernier, or the least count, is the difference in length between one division on the main scale and one on the vernier.

A vernier is said to be **direct** when the divisions on the vernier are smaller than those on the main scale Fig. 21 A; **retrograde,** when the divisons on the vernier are greater than those on the main scale. See Fig. 21B.

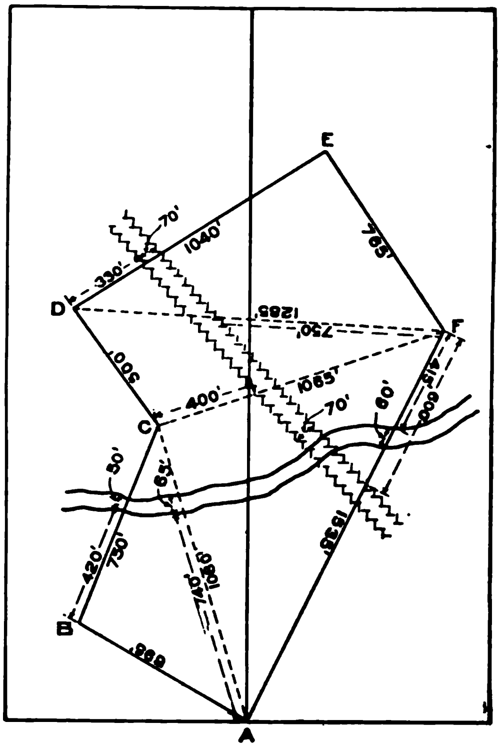


Fig. 20.

In Fig. 22 let MM represent a scale divided into tenths; then since ten spaces on the vernier VV are equal to nine spaces upon the scale, it is evident that each space upon VV is short by one-tenth of a space of MM. The least count is therefore, $\frac{1}{10}$ of $\frac{1}{10}$ or $\frac{1}{100}$.

The vernier and slow motion screw of the vertical arc of the engineer's transit are attached to the left hand standard of the instrument.

Fig. 23 represents a vernier as applied to an engineer's transit. It will be noticed that the main scale is divided so as to read directly to 30 minutes. The vernier is so divided that 29 spaces upon the main scale equal 30 spaces upon the vernier, therefore the least count of the vernier is $\frac{1}{30}$ of 30 minutes or 1 minute.

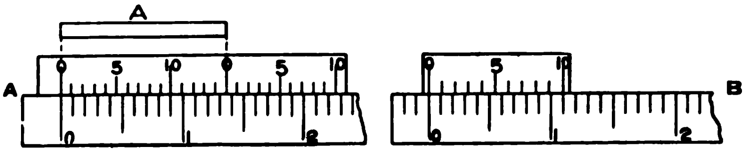


Fig. 21.

It will be apparent, therefore, that the readings are taken in the direction of the increasing graduations of the main scale. Thus, for example, in Fig. 23, it will be noted that the zero *a*, has passed the 156th space on the main scale, and is near the 30 minute (half degree) division *b*, therefore the coinciding lines of the vernier and main scale must be between 0 and 30′, and we

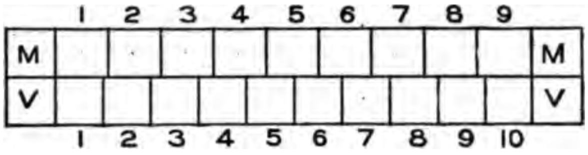


Fig. 22.

find them, by looking along the scale of the vernier, at 17 minutes hence, the reading is $156^\circ\ 00' + 17' = 156^\circ\ 17'$.

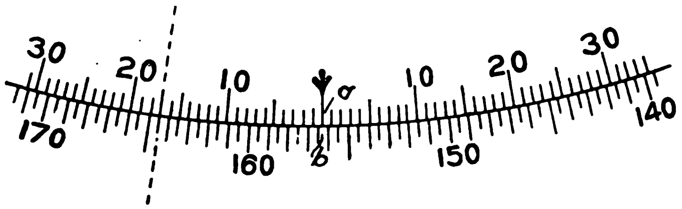


Fig. 23.

Fig. 24 represents another method of division of the circle of the transit. The vernier is double, and the figures on the vernier are inclined in the same direction as the figures on the scale to which they belong.

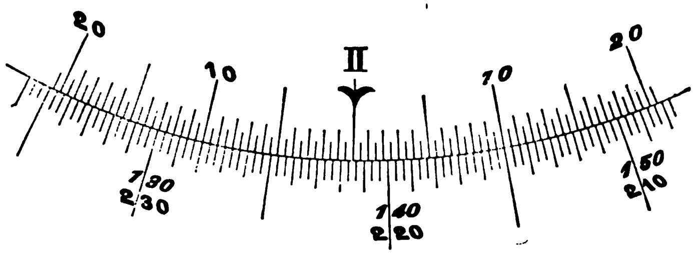


Fig. 24.

It will be noticed that the main scale reads directly to 20 minutes and that the vernier is so divided that 39 spaces upon the scale correspond to 40 spaces upon the vernier. The least count of the vernier is therefore $\frac{1}{40}$ of 20 minutes or $\frac{20}{40}$ of 1 minute equals 30 seconds.

To read the inside scale, it will be noticed the zero of the vernier is beyond the 138° mark and about half way between the first and second 20′ divisions. The reading so far is then 138° 20′. Now look along the vernier to the right until a line upon the vernier is found that seems to be a prolongation of a line upon the scale. This occurs at the division marked 10 upon the vernier so that the reading is 138° 20′ + 10′ or 138° 30′.

For the outside scale, the zero of the vernier is beyond the 221° mark and about half way between the first and second 20′ divisions. The reading so far is therefore 221° 20′. Now look along the vernier to the left as before, and the divisions coincide at the division marked 10 upon the vernier, so that the reading of the outside scale is 221° 20′ + 10′ or 221° 30′. The sum of the readings of the two scales equals 360° as it should.

EXAMPLES FOR PRACTICE.

1. Determine the least count of the vernier in Fig. A, 39 spaces upon the scale, being equal to 40 spaces upon the vernier.

2. Determine the least count of the vernier in Fig. B, 59 spaces upon the scale being equal to 60 spaces upon the vernier. The figure represents what is called a *folding vernier*. To read it follow along the vernier in the usual way until the division marked 10 is reached. If there are no corresponding lines, then go back to the other end of the vernier beginning with the other 10 mark and follow it back toward the center of the vernier.

3. Determine the least count of the vernier of Fig. C, which represents the usual method of dividing the vertical circle of the transit.

The Level Bubble is one of the most important attachments of an engineering instrument, and an instrument otherwise good may be rendered useless by imperfect level tubes.

The spirit level is a glass tube nearly filled with a mixture of ether and alcohol, the remaining space being occupied with the vapor of ether. Alcohol alone has not proved satisfactory as it is too sluggish in its movements, thereby rendering an instrument lacking in sensitiveness. If the tube were perfectly cylindrical, the bubble would occupy the entire length of the tube, when horizontal, or when slightly inclined to the horizon, thus rendering it impossible to tell when the tube is in a truly horizontal position.

The tube is, therefore, ground on the inside so that a longitudinal section is a segment of a circle. If the tube is not ground to an an even curvature the bubble will not travel the same distance for every minute of arc to the extreme ends of the tube, and an otherwise perfect instrument will not work well.

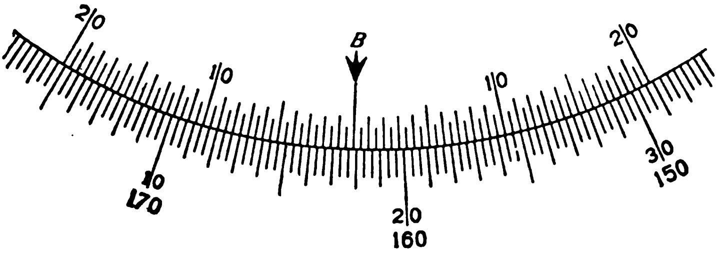


Fig. A.

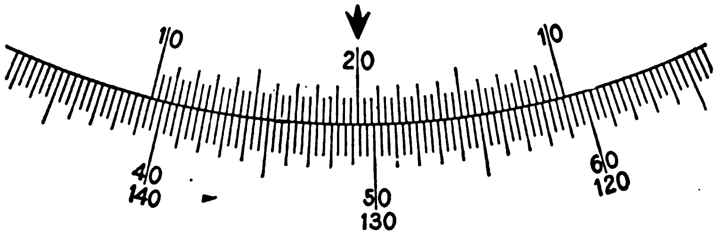


Fig. B.

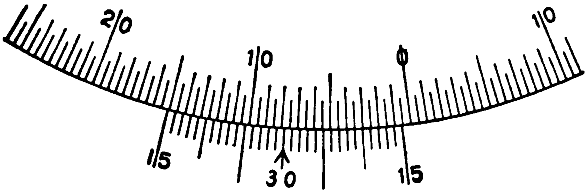


Fig. C.

A line tangent to the circular arc at its highest point, as indicated by the middle of the bubble, or a line parallel to this tangent, is called the axis of the bubble tube. This axis will be horizontal when the bubble is in the center of the tube. Should the axis be slightly inclined to the horizontal, the bubble will move toward the higher end of the tube, and the movement of the bubble should be proportional to the angle made by the axis with the horizontal. Therefore if the tube is graduated, being a portion of the circumference of a circle, with a radius so large that the arc of a few seconds is of an appreciable length, it will be possible to determine the angle that the axis may make at any time with the horizontal, provided the angular value of one of the divisions of the tube is known. This is done by noting by how many divisions the center of the bubble has moved from the center of the tube.

Since divisions of uniform length will cover arcs of less angular value as the radius of the tube increases, and since a bubble with a given bubble space will become more elongated as the radius is increased, the sensitiveness of the bubble is proportional to the radius of curvature of the tube and the length of the bubble. The length of the bubble, however, will change with changes in temperature, becoming longer in cold weather and shorter in warm weather. This is due to the fact that the liquid in the tube expands and contracts more rapidly than the glass. If the bubble contracts excessively, the sensitiveness is thereby impaired, and it should be possible to regulate the amount of liquid in the tube. This is done by means of a partition at one end, having a small hole in it at the bottom. A bubble should come to rest quickly, but should respond easily and quickly to the slightest change of inclination of the tube.

To determine the radius of curvature of the tube, proceed as follows: Let S = length of the arc over which the bubble moves for an inclination of 1 second. Let R = its radius of curvature.

$$\text{Then } S : 2\pi R :: 1'' : 360°.$$

From which $R = 206265 \times S$ Or $S = \frac{R}{206265}$

S may be found by trial, the level being attached to a finely divided circle. Or, bring the bubble to the center and sight to a divided rod; raise or lower one end of the level and again sight upon the rod. Call the difference of the readings h, the distance of the rod d, and the space which the bubble moved S. Then from approximately similar triangles

$$r = \frac{d\,S}{h}$$

EXAMPLE FOR PRACTICE.

1. At 100 feet distant, the difference of readings was 0.02 foot, and the bubble moved 0.01 foot. What is the radius of the bubble tube? Ans. 50 feet.

Locke's Hand Level. This instrument consists of a brass tube six inches long with a small level mounted on its top at one side of the center near the object end. See Fig. 25. Underneath the level is an aperture across which is stretched a horizontal wire attached to a frame. This frame is made adjustable by a screw and a spring working against each other, or by two opposing screws placed at the ends of the level mounting. In the tube, directly below the level, and at 45° to the line of sight, is placed a totally reflecting prism acting as a mirror. The images of the bubble and wire are thus reflected to the eye. The prism divides the section of the tube into two halves, in one of which is seen the bubble and wire focussed sharply by a convex lens placed in the draw tube at the eye end of the instrument, while the other permits of an open view. Putting the instrument to the eye and raising and lowering the object end until the bubble is bisected by the horizontal wire, natural objects in the field of view can be seen through the open half at the same time, and approximate levels can then be taken. To prevent dust and dampness from entering the main tube, both the object and the eye ends are closed with plain glass.

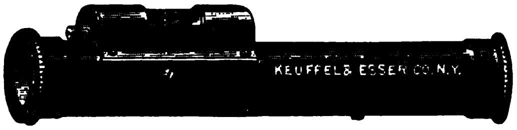


Fig. 25.

There are two adjustments necessary in this instrument: First, the bubble tube: it should be so adjusted that the bubble will be in the center of the tube when the instrument is horizontal. Second, the horizontal wire; it should bisect the bubble when the latter is in the center of the tube. The methods of executing these adjustments are so apparent it will be unnecessary to dwell upon them here.

The instrument is intended to be carried in the pocket and is of especial value upon reconnaissance surveys, and for sketching in topography upon preliminary surveys.

For topographical purposes, the topographer should provide a rod about eight feet long, divided into foot lengths, the divisions painted alternately red and white. Upon this rod, the topographer should mark by a notch or other means, the height of his eye above the ground. Standing then upon a station of the line of survey, the topographer directs his assistant to carry the rod out upon either side of the line and in a direction at right angles thereto, until a point having the proper elevation above or below the center line is found as determined by the topographer holding the instrument in a horizontal position at the eye. The topographer then paces the distance, while the assistant carries the rod to the next point. It is evident that if the line of sight from the instrument coincides with the mark upon the rod, the two points upon the ground are at the same level. If the line of sight strikes the rod, say one foot below the mark upon the rod, it is evident that the ground where the rod is held is one foot higher than where the instrument is held. These operations can be repeated indefinitely and made to extend as far as necessary upon either side of the line. The points of proper and equal elevation are then connected forming contour lines, but the topographer should fill in details by the eye. The methods of keeping the field notes will be illustrated and described later.

Let BCXDEFG and H, Fig. 26, represent the successive rod readings on the right of the center line A, and B′ C′ D′ E′ F′ G′ the readings on the left. Now suppose the leveler stands with a Locke-level at zero and the rod is held vertically at B. The line of sight *ab* bisects the rod at 8.6 feet. The distance from the ground to the observer's eye is 5.5 feet. Thus it is apparent the elevation at B will be 3.1 feet lower than at A. The observer now paces the distance between A and B, and finds it to be 50 feet. The reading is now taken at C on the line of sight *cd* which reads 6.2 feet, hence the elevation of C is .7 foot lower than B, and the distance between 20 feet. Suppose an attempt is made to take a reading near D. Since the horizontal plane from the observer's eye to the ground does not strike the rod, it is apparent that the rod is too far away, therefore it should be moved back to a point X where the horizontal plane *ef* will bisect the rod at some division. The elevation of X having been ascertained, pace the distance CX, as in the former cases. This method is continued until H is reached, taking the rod readings at *g h*, *i j*, *k l*, *m n*, and *s y* and pacing

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CAMP OF A SURVEYING PARTY

the distance between each. The same method is used on the left-hand side of the center line. However, where the surface of the ground has an abrupt change between stations, it is customary to take cross sections at such changes and ascertain the distances between the stations by pacing; the center line at such points is accepted as zero; in the same manner perform the operation as if at a station. Where a cross road intersects the center line or any portion of the cross section, take readings at places that show an abrupt change, as the top of a bank, side of the road, or gutter, center of the road and on the other side in the same way and place as before. This rule holds good in places where small streams are situated. It is not necessary to find the depth of the water, because the purpose of the cross section deals solely with the surface. Where obstacles prevent the section being run at right angles to the center line, use the method of off-sets and secure the desired elevation as closely approximate as circumstances will permit.

The Abney Hand-Level and Clinometer. This instrument is similar to the Locke hand-level, see Fig. 27, but the small spirit level mounted on top can be moved in the vertical plane and is clamped to a dial graduated upon one side into single degrees and upon the other into slope ratios, so that it is possible to measure angles of slope.

The adjustments of the instrument are the same as for the Locke hand-level.

The instrument can be used in the field

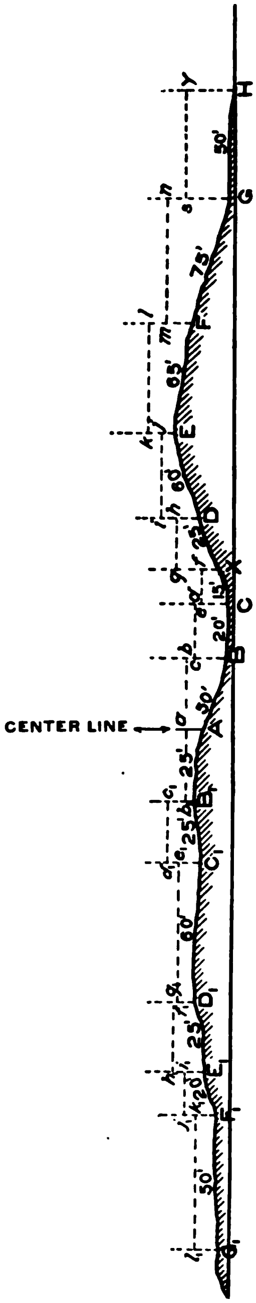


Fig. 26.

in the same manner as the Locke hand-level, but is of more universal application. It is of especial value upon steep slopes when the efficiency of the Locke level would be limited by the length of rod. In using the Abney instrument it is only necessary to mark the height of the eyes upon the rod. In sighting upon the rod, with the horizontal line coinciding with the mark upon the rod, move the vertical circle until the bubble is in the center of the tube. Read the vertical angle, and the tangent of this angle multiplied by the horizontal distance to the rod will give the difference of elevation. If the distance to the rod is measured along the slope of the ground, multiply this distance by the sine of the vertical angle to get the difference of elevation.

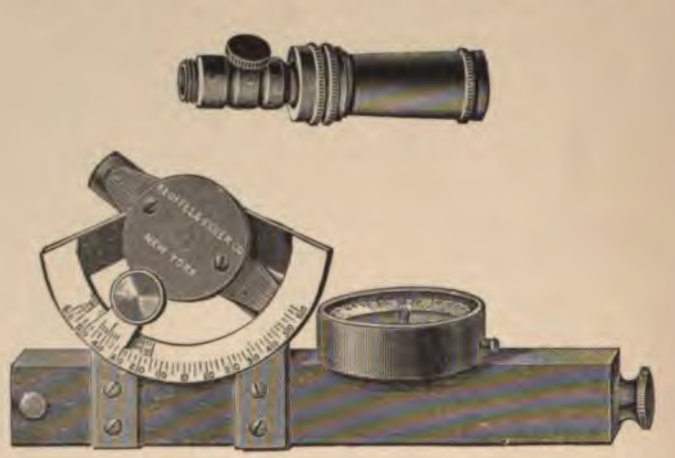


Fig. 27.

The most satisfactory method of using this instrument is in connection with a straight edge from 8 to 10 feet in length. The straight edge is laid upon the ground parallel to the direction of slope and the clinometer is then applied to it, the vertical circle being turned till the bubble is in the center. The angle of slope is then read, or better still, the slope ratio is read from the vertical circle. This operation is repeated at every change of slope, the distances being either paced or measured with a tape. For instance, suppose the slope is found to be 60 feet in length and the slope ratio as given by the clinometer is $\frac{1}{10}$. It is evident then that at the end of the slope the difference in elevation will be 6 feet. The instrument is sometimes fitted with a small compass and a socket for use upon a tripod or Jacob staff.

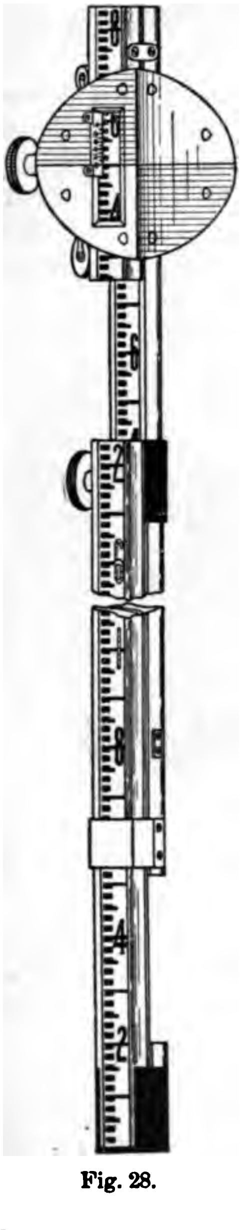


Fig. 28.

The Leveling Rod is an important part of the leveling outfit; it is used in measuring the vertical distance between the horizontal plane through the line of sight and the point upon which the rod is held. There are three forms in common use known as the New York, Philadelphia and Boston. They are made of hard wood 6½ feet long, sliding out to 12 feet and provided with target, vernier and clamps.

Leveling rods are of two kinds, the target and the self-reading. Of the target rods, the New York and Boston are generally used for precise work. Of the self-reading rods, the Philadelphia shown in Fig. 28 is in more common use. The self-reading rods are used only in connection with that class of work where approximate accuracy only is required; this form is generally read to hundredths of a foot and can be read directly from the instrument by the observer without the aid of the target, as is suggested by the name. However, with the aid of the target this rod can be read to thousandths of a foot approximately. The target is used when greater accuracy is required and when the rod is so far from the instrument that it cannot be distinctly read.

The rod consists of a graduated scale divided into feet, tenths and hundredths of a foot, and when properly made, readings to thousandths of a foot can be easily taken. The numbers making the tenths should be 0.06 foot long and so placed that one-half the length is above and one-half below the line. The numbers marking the feet are 0.10 foot long and each is bisected by the foot mark.

This class of rod is painted white, the foot graduations are red and the tenths and hundredths are black horizontal lines.

No attempt will be made to describe the reading of the vernier of either the New York or Boston rod, but the Philadelphia rod is so divided as to make its reading easily understood. With this rod each side of the black horizontal line indicates 100ths, that is, the lower side of the first black space is called "one," and the upper side of the same space is called "two," the lower side of the third space is called "three" and so on until the tenth is read.

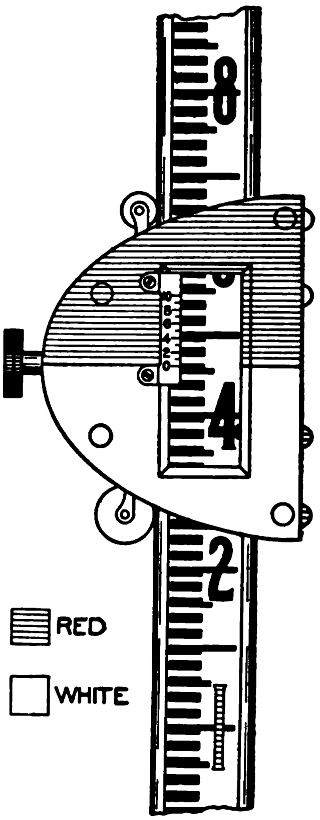
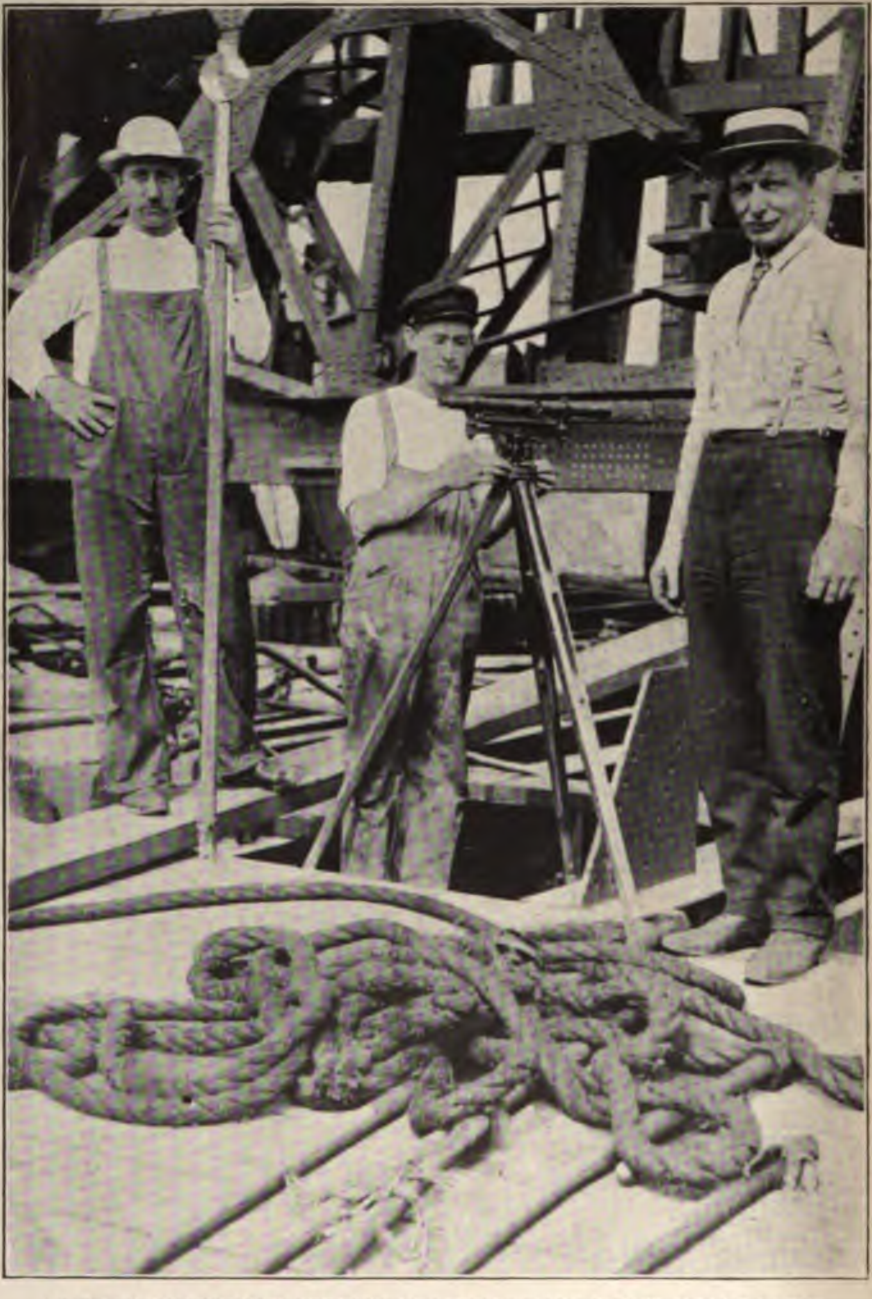


Fig. 29.

The reading is taken without the aid of the target, in feet, tenths and hundredths as the case may be. The movable target has a vernier which reads to thousandths of a foot and is read from zero to ten. To read this rod, move the target to any convenient place on the scale of the rod and note where the vernier at zero coincides with a black horizontal line ; then note where a line of the vernier coincides with a line of the scale. For example, if the zero of the vernier is just above one foot, four-tenths and five hundredths, as shown in Fig. 29, and a line of the graduation of the vernier coincides at 7 with a horizontal black line on the rod, the reading will be 1.457 as is shown in Fig. 29. If reading to the nearest 100th, the reading will be 1.46. This is because the 7 naturally brings the zero .002 above the line of graduation on the rod, therefore, the zero of the vernier is .002 nearer the 6 than the 5, hence, the reading is as above. Should the vernier read .002 instead of .007 the reading would be 1.45. It is apparent that .002 now brings the zero of the vernier below the line, hence it will be nearer to the 5 than the 6, thus the



LEVELER AND RODMAN ENGAGED IN BASCULE BRIDGE CONSTRUCTION OVER CHICAGO RIVER, CHICAGO, ILLINOIS rod reading is 1.45. Therefore, in all readings with the Philadelphia rod, read the thousandths to the nearest half hundredth. This is true whether or not the lines coincide.

These readings apply only to the face of the rod or to 6½ feet. When the rod is extended to 12 feet, or any fractional part thereof, the reading is a little different, both as to its graduation and vernier. The scale, of course, is the same on the face of the rod when extended, except as to the vernier, which is placed on the back at 6½ feet and the scale of graduation on the extended part of the rod is also on the back of the extension which runs through the vernier, as shown in Fig. 30. The scale of hundredths is the only part to be particularly observed, together with the vernier in the former.

For example, the first horizontal black space equals "one," which is the top line of the foot mark. The lower side of the first black space is "two," and the upper side of the same space is "three" hundredths, and so on until the tenth is reached. The tenth and feet are placed the same as on the face of the rod. The vernier, as already stated, is a little different in point of reading and is graduated from ten to zero, instead of zero to ten, as on the movable target. However, with some recently-made rods of this type, the scale and vernier reading is the same throughout. See Fig. 31. The graduation at ten is taken as the zero in determining thousandths. The vernier in question is firmly attached to the upper end of the rod 6½ feet, (and the extension of the rod runs through this vernier). The differences in graduation of the two sides should be carefully noted. The rod has two clamp screws, one attached to the movable target and the other near the vernier on the back of the rod. In running the rod, it is customary, where a target or rod reading exceeding 6½ feet is

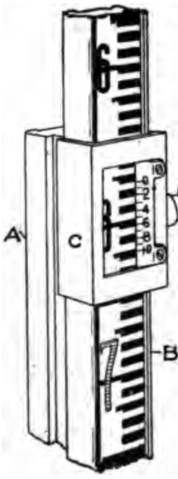


Fig. 30.

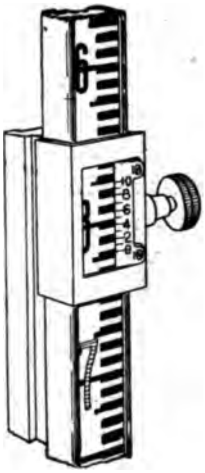


Fig. 31.

desired, to set the target at 6½ feet and run the rod to its full length, then move down as signalled; where no target reading is required, run the rod to its full extent (12 feet) and as the face of the rod has a scale throughout, the reading can be taken from the instrument.

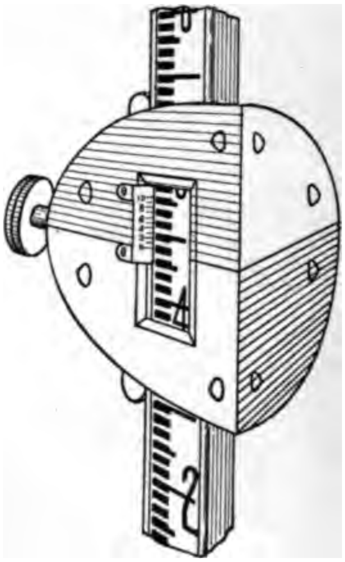


Fig. 32.

Should the instrument not be near enough to enable the leveler to see the rod distinctly without the aid of the target, he should first read the rod through the telescope of the instrument and then notify the rodman at what distance the intersection of the cross-hairs in the instrument approximately bisects the rod, such as 3.21, which means three feet, two tenths and one hundredth. The rodman then sets his rod to read this distance and another sight is taken, being careful to have the rod plumb. Should the intersection of the target fail to coincide with the cross-hairs in the instrument, the leveler then signals, or calls out if sufficiently near to do so, the true rod reading, as up a tenth, down two hundredths, as the case may be, and the target is placed at this distance. When precision is required, this method is relied upon only for the approximate placing of the target; the method used in this case is to slowly move the target by standing behind the rod and holding it between the thumb and fingers of one hand, while the target is moved with the other. Then the target is slowly moved by the signals of the observer.

When a slow motion with the hand above the shoulder or below the hip is made by the observer, it means that the rod is to be moved in that direction a fractional part, as one tenth, but when a quick motion is made and the hand drawn back in the same manner it implies that the target is to be moved just a trifle. In this way and by proper attention to the signals of the observer, the rodman can become an efficient and helpful assistant, thereby saving much time. When the target is finally set, the rodman reads the rod and calls out the reading to the observer, when within reasonable distance. The target rods are read entirely by the rodman, and the readings are kept by him in a note book for that purpose; these notes should be given to the observer at every opportunity and results checked. To obtain correct results when leveling, it is absolutely essential that the rod be vertical and the rodman should remember to hold the rod in this position.

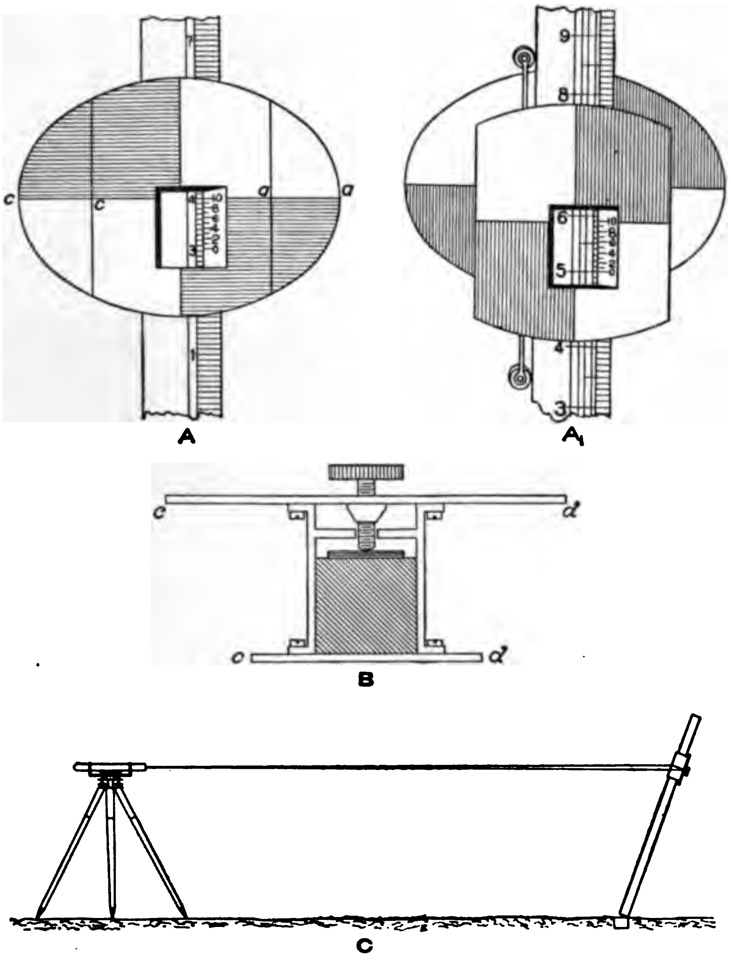


Fig. 33.

The observer or leveler, by means of the vertical wire upon the target of an ordinary leveling rod, can tell whether or not a rod is vertical and in a position at right angles to the line of sight, but he is not able to determine whether the top of the rod is inclined towards the instrument or in the opposite direction; because when looking through the telescope of a level he can see only a fractional part of the rod. Therefore the necessity of overcoming this difficulty led to the invention of the bent target which obviates this latter trouble as can readily be seen from Fig. 32. The American target fulfills the same requirements, but differs from the ordinary target in having two discs, one behind the other, as in Fig. 33. The principle of construction of this target is extremely simple, and may be best explained in the figures above Suppose a target of the old kind, which in its front view looks exactly like the front view of the new target in A, to be cut along the vertical lines *aa*, *bb*, thus dividing it into three parts; that is, one center-piece and two wings. Suppose furthermore, the centerpiece to remain in its former place at the front of the rod, while the two wings are removed to the rear of the rod. Then the result evidently will be that the horizontal line *cc*, *dd*, will appear as one unbroken line to the observer, only when the rod is held perfectly vertical. Any deviation either towards the instrument, or away from it will cause the two parts *cc* and *dd* of the horizontal line situated at the rear of the rod in the wings of the target to show either above or below that part *cd* of the horizontal line which is situated in the front of the rod in the centerpiece of the target.

Whether using the bent target, the ordinary target or no target at all, it is apparent that the rodman should hold the rod in a vertical position, known as plumb. This can be done by standing directly behind the rod with both feet together or apart, as the rays of the sun may require, governing shadows, and holding the rod between the thumb and finger of one hand while moving the target with the other. After the target is set, both hands are brought in line with the shoulders, and standing erect, the hand should touch the rod very lightly, so that it will almost stand in a vertical position by itself; or when standing in that position if the center of the rod or the corner is made to coincide perpendicularly with the nose and chin, it will be plumb. The rodman should never put his hands around the rod.

Another way is to sight along the line of some building apparently in line. There are, of course, many different methods of signalling, but the ones mentioned are frequently used.

When the rod is to be read without the aid of a target or with the ordinary target, it frequently happens that the rod is not vertical and the signal used for bringing it in its proper vertical plane is the raising of either the right or left hand in a vertical position, which indicates that the rod should be inclined in that direction. In so doing move the rod slowly until the hand is lowered. After the target has been set in its proper position, clamp it by the screw on its side, then give another sight and note the signals of the observer.

If the target is to be moved, the observer should hold the palm of one hand in the direction the target is to be moved. The observer should use but one hand in signalling the rod; if the target is to be lowered, he should hold his hand below his hip, palm down. To raise the target he should hold his hands above his shoulder, palm up. Any considerable change in the position of the target is denoted by a more or less violent motion of the hand. If a very slight change is desired, the observer should hold his hand in the proper position without moving it up or down. When the proper position of the target has been obtained, the observer indicates the fact by raising both arms above the head and moving them in the arc of a circle to indicate that the rod reading at that particular place is complete.

New York Rod. This rod resembles the Philadelphia rod as to its use and dimensions, but differs as to scale and vernier reading. The scale is divided into feet, tenths and hundredths, the same as the Philadelphia rod, except the graduations of the hundredths, which instead of having the sides of one black space each equivalent to 0.01 foot, as on the Philadelphia rod, the hundredths are distinct by themselves, therefore, each line between the tenth is .01 part of the scale. Fig. 34 shows the rod at its full length, and Fig. 35 shows a sectional part thereof with its movable target set at 6½ feet and the black horizontal lines each indicate .01 as more fully explained hereafter. Fig. 36 shows the side with its graduations, as on the face of the rod and is set at 6½ feet.

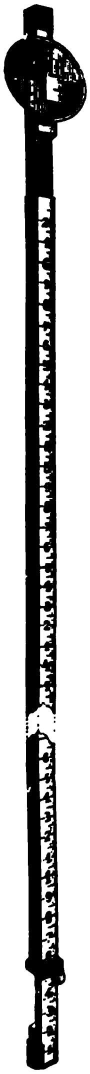


Fig. 34.

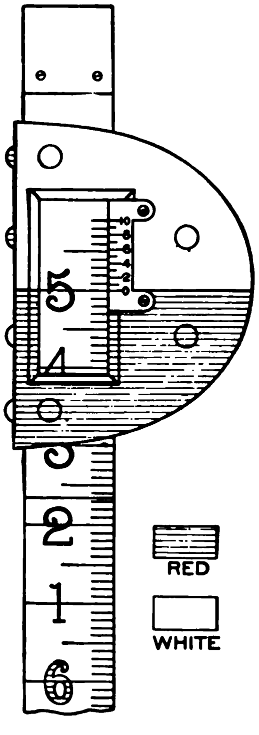


Fig. 35.

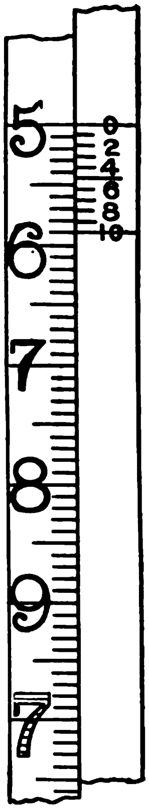


Fig. 36.

The rod has a movable target which carries a vernier, and allows readings to thousandths. It cannot, however, be read without the aid of the target and is used for the most part, where precision is required; it probably commends itself to a greater number of engineers, because of its stiffness and wearing qualities. For elevations up to 6½ feet, the target is used in the same manner as the former rod by sliding it up or down upon the rod. Above 6½ feet, as with all the rods, the target is clamped at the 6½-foot division. The back of the rod slides upon the front half and when so extended the vernier is on each of the narrow sides, impressed in the wood (See Fig. 36). It should be noted that while the vernier on the Philadelphia rod is situated on the back when extended, with the New York rod it is on its narrow sides. The vernier in question is somewhat different from the one found on the Philadelphia rod, since it is provided with a direct vernier, while the other is provided with an indirect vernier. The former, as has been explained, is usually placed below the center of the target, that is, the zero is placed below the intersection of the horizontal and vertical lines of the target. In almost every case this causes confusion because the rodman has been taught, by reason of using a Philadelphia target rod, to read the scale at the zero of the vernier to the fractional parts of a foot by looking along the vernier for the coinciding lines. There need be very little confusion in reading the New York rod, if it is remembered that the center of the target is set by the leveler and not the zero of the vernier as on the Philadelphia rod. Careful observation of the vernier will show that the zero of the vernier is placed at the intersection of the horizontal and vertical lines of the target. The method of using the clamps, setting the target, etc., is the same as that of the Philadelphia rod.

The Boston Rod is made of mahogany, is of the same length and slides out as the rods just described. It is distinctly a target rod and cannot be read without its aid. The scale and vernier, however, are on the narrow sides and can be read to thousandths or any fractional part of a foot. The target is fixed upon one-half of the rod for elevations less than 6½ feet. The target end is held upon the ground and the front of the rod slides upon the back, as shown in Fig. 37. Above 6½ feet the rod is inverted as shown in Fig. 38, and is then used in much the same way as the New York rod. The figures above referred to show the sides of the rod with its scale upon it. The screws at each end act as clamps. In the old style of Boston rod a wooden target was screwed to the rod with the result that the target would warp and twist or be knocked off, thus rendering the rod useless. The best type of Boston rod is fitted with a bent metal target. This form is very serviceable and satisfactory. It will be apparent from the foregoing description that the rod is read altogether by vernier, the scales and vernier being on the side. It is the lightest and neatest rod of the three but the least used.

Cross-Section Rod. This is a rod 10 feet in length, painted white, with black graduations; it is divided into feet, tenths and hundredths, (See Fig. 39). The scale is on both sides. At each end is a spirit level bubble with graduations on the upper side of the tube to bring the rod in a horizontal plane. In the center of the rod is an opening for the hand, and thereby it can be easily taken from place to place. The purpose of this rod is to simplify the lengthy calculations in taking cross sections; this will be more fully explained under its respective head.

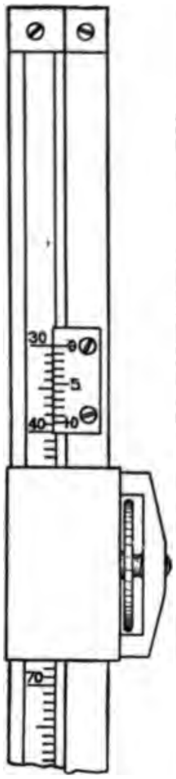


Fig. 37.

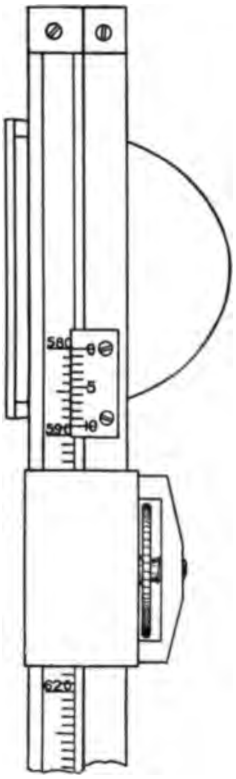


Fig. 38.

In Fig. 39 A and B are the bubbles. It is apparent that if one end of the rod is placed on the side of a hill and the other raised in a vertical position until the bubble appears in the center of the tube, the base of the rod will be in a horizontal plane.

Ranging Poles. Fig. 40 shows the three forms of ranging poles (called flags) in common use, all of which are from 6 to 10 feet in length, made of hardwood, octagonal in shape; they are tapered from the top down and each foot painted alternately red and white, and provided with steel shoes, except the smallest one, which consists of an iron tubular rod $\frac{7}{8}$-inches in diameter and used for the most part on construction work. These flags are for the purpose of establishing points or retaining a given line indefinitely; it is an important tool of the surveyor's outfit. To use this flag, it is placed approximately at some reasonable distance from the instrument and then by the signals of the observer is moved until the line of sight through the instrument bisects it. It should be held in a vertical position and governed by the same methods used in placing a leveling rod in a vertical position. It is also a convenient device for measuring, approximately, distances not exceeding six feet, but where any great amount of accuracy is desired, the method should not be relied upon. It is an advantage, however, to use the flag as a check, when it may appear that some discrepancy has occurred.

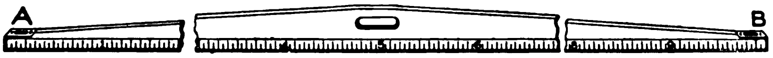


Fig. 39.

INSTRUMENTS.

The Wye Level. There are three kinds of leveling instruments in common use, viz: The Wye level with four leveling screws, the Wye level with three leveling screws and the Dumpy level. The Wye level derives its name from the vertical forked arms, called Wyes, in which the telescope rests. It is clamped to them by collars which may be raised allowing the telescope to be turned on its horizontal axis or lifted out entirely. It is also referred to as the four-screw level. Like other levels it is used for the purpose of ascertaining a horizontal line of sight parallel to a spirit level and perpendicular to the vertical axis. The line of sight is fixed in the telescope by the intersection of cross-hairs. A spirit level is attached to the under side of the telescope and is protected except on top by a metal tube. In the barrel of the telescope slide two tubes, in one of which is an eye-piece; in the other is the objective.

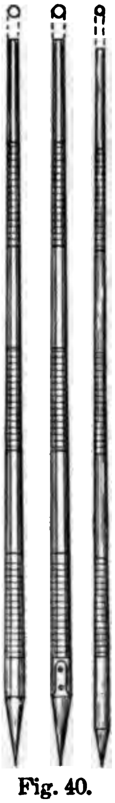
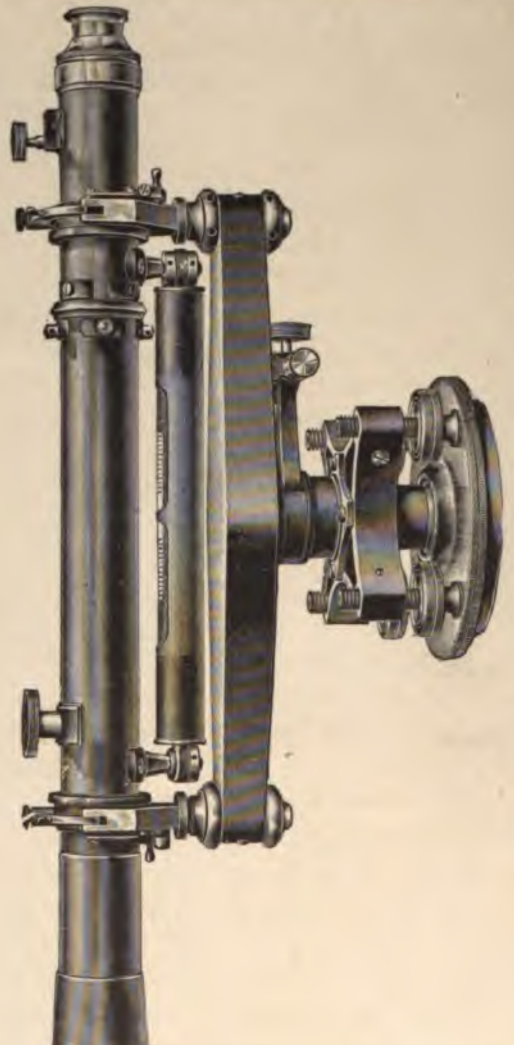
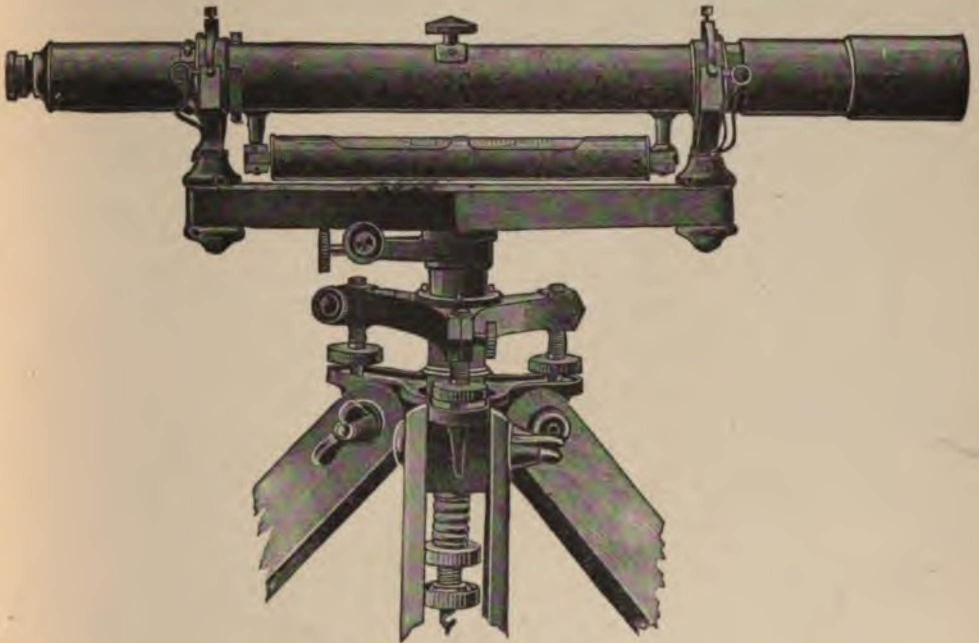


Fig. 40.

The *eye-piece* usually found with the four-screw leveling instrument is of the erecting type. The inverting eye-piece as distinguished from the erecting eye-piece has two lenses instead of four. The result is that the inverting eye-piece permits more light to reach the eye of the observer, and is therefore better adapted to precise leveling. At first some inconvenience is experienced by the fact that all objects are upside down, but a little experience will soon convince the observer that all the advantages whether for a four-screw instrument or a three-screw instrument, lie with the inverting eye-piece. Nearly all makers give a purchaser his choice of the style of eye-piece without extra charge. In purchasing an instrument it should be noticed whether the eye-piece is adjusted by a straight pull or by a spiral motion, because the spiral motion is usually considered more satisfactory.



WYE LEVEL—FOUR SCREW.



WYE LEVEL—THREE SCREW.

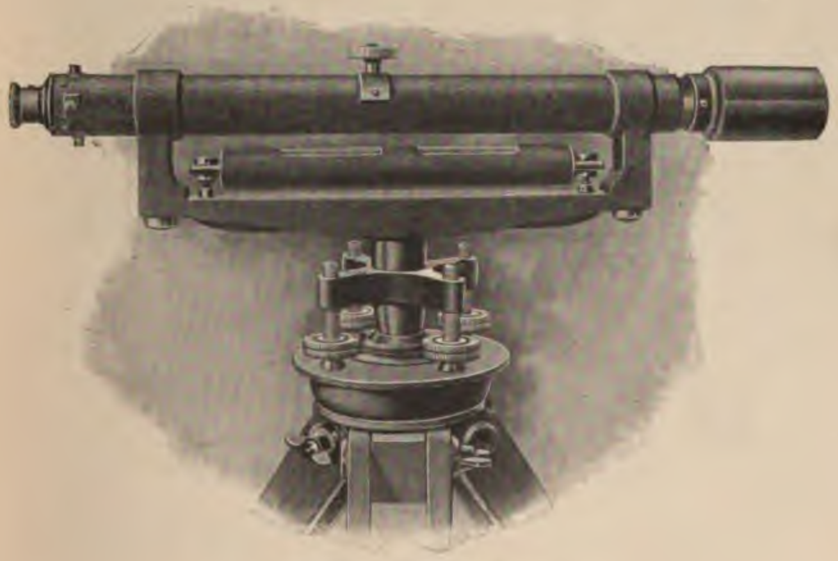


Fig. 41. DUMPY LEVEL.

An inexperienced observer upon looking through the level and finding no cross-hairs may suspect that the cross-hairs are broken. It must not be forgotten that the eye-piece must be focused before the cross-hairs will come into the range of vision. Having once focused the eye-piece upon the cross-hairs, the adjustment will stand for a long time if the eye-piece is undisturbed.

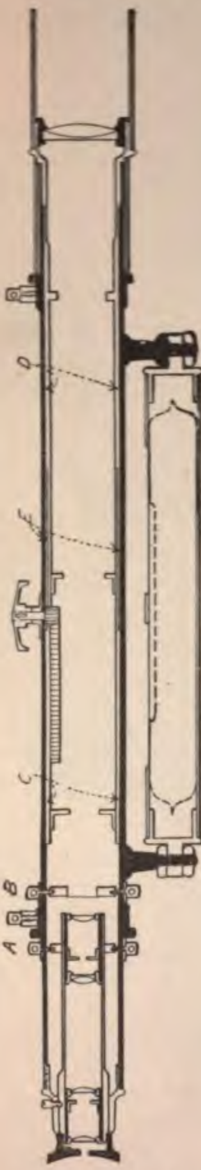


Fig. 42. Section, 18-inch Wye Level.

The object glass is moved in and out by means of a pinion which works on a rack attached to a sliding tube and moves in the axis of the barrel, passing through the run which is inclined in the barrel. The instrument is provided with a clamp, slow motion and leveling screws and mounted on a tripod. The two former screws are situated directly under the horizontal bar and revolve with the telescope.

The Line of Collimation of a level is the line joining the optical center of the object-glass and the intersection of the cross-hairs, and since this line determines the point towards which the telescope is directed, it should coincide with the optical axis of the telescope. The eye-piece and object-glass must be accurately centered.

Instrumental Parallax is an important condition of focusing due to the fact that the image does not fall in the plane of the cross-hairs.

To determine this, direct the telescope upon an object and focus the eye-piece so that the cross-hairs are perfectly distinct. Then turn the telescope upon the object which is to be observed, and focus the object glass until the image is clearly defined. Move the eye from side to side and note whether there is any apparent movement of the cross-hairs and image. If any is seen, the two operations are to be repeated until all parallax is removed.

This adjustment depends upon the eye of the observer and when made for one person may not be correct for another.

Spherical Aberration. This defect is caused by combining lenses of different curvatures so that objects on the side of a field of view are seen less distinctly than those in the center. To test the object glass for this defect cover the outer edge with an annular ring of paper and focus upon some desired object. Then remove the ring and cover the central spot of the glass; if no change of focus is needed the glass has no spherical aberration.

To test the eye-piece, sight to a heavy black line drawn on white paper and held near the side of the field of view. If it appears perfectly straight the eye-glass is a good one.

Chromatic Aberration is a defect caused by combining lenses of different and improper varieties of glass so that the yellow or purple colors appear on the edge of the field. To test the telescope for this defect focus it upon a bright distant spot and slowly move the object glass out and in. If no colors are observed around the edge of the field of view the telescope is free from this defect.

Adjustments. The adjustments of the Wye-level are three in number and should be made in the following order:

1. To make the line of collimation parallel to the bottoms of the collars.
2. To make the axis of the bubble tube parallel to the line of collimation.
3. To make the axis of the bubble tube perpendicular to the vertical axis of the instrument.

To make the test for the first adjustment set up the instrument firmly upon solid ground, shaded from sun and wind. Direct the telescope towards the side of a building, a fence or other convenient object and carefully center the intersection of the cross-hairs upon a well-defined point, such as the head of a tack. Clamp the vertical axis and loosen the telescope clips. Now slowly revolve the telescope in the wyes and note if the intersection of the cross-hairs continues to cover the point. If so, the line of collimation is in adjustment.

If the intersection of the cross-hairs moves off the point, revolve the telescope in the wyes as nearly as possible through 180 degrees and carefully center a point at the intersection of the cross-hairs in this last position. Bisect the distance between the two points and establish a third point: by means of the screws attached to the cross-hair diaphragm, move the diaphragm so that the intersection of the cross-hairs covers the third point. Now repeat the test and correct the position of the cross-hair diaphragm until the intersection of the cross-hairs covers one point as the telescope is revolved in the wyes.

The horizontal cross-hair should at all points be at the same distance from the bottoms of the collars. To test this, carefully center one extremity of the hair upon a point, and by means of the tangent screw, slowly revolve the telescope upon the vertical axis, and if the hair covers the point from end to end, the adjustment is complete. If it does not, the hair is to be adjusted by the same screws as before. Making this adjustment will probably disturb the former one, and the two are to be repeated in succession until satisfactory.

It will be noticed that to make this adjustment, it is not necessary to level the instrument.

Adjustment of the Axis of the Bubble-tube. To test this adjustment, first throw back the clips holding the telescope in the wyes, and then revolve the telescope upon the vertical axis to bring it directly over a pair of leveling screws and clamp the axis firmly. By means of these leveling screws bring the bubble to the center of the tube as accurately as possible. Now without disturbing the instrument, carefully lift the telescope out of the wyes and turn it end for end, being careful when replaced in the wyes that the telescope comes to its seat at each end. If the bubble in this new position of the telescope comes to rest at the center of the tube, the axis of the tube is in adjustment.

If the bubble does not return to the center, bring it one-half way back to the center by means of the vertical screws at one end of the bubble-tube, and the remainder of the way by the two leveling screws. Now repeat the test and correction as often as necessary until the bubble remains in the center of the tube.

Having adjusted the bubble-tube over one pair of screws, test it over he other pair.

When the horizontal hair is truly horizontal, the line of collimation and the axis of the bubble-tube should be in the same vertical plane. To test this, after the previous adjustment has been completed, loosen the clips of the wyes and bring the bubble carefully to the center of the tube. Now slowly revolve the telescope in the wyes and note if the bubble still remains in the center of the tube. If it does, the line of collimation and the axis of the tube are in the same plane. If the bubble runs to one end of the tube, bring it back by the horizontal screws attached to one end of the tube.

It must be borne in mind that the first and second adjustments must be carefully made and that they are absolutely essential if satisfactory results are to be attained with the instrument.

Adjustment of the Vertical Axis. This adjustment is not absolutely essential, provided that every time a reading is taken the bubble is brought to the center of the tube by means of the parallel plate screws. However, the adjustment will expedite field work and should always be made.

To test, level the instrument carefully over both pairs of screws; if the bubble remains in the center of the tube as the telescope is revolved on the vertical axis all the way round, the adjustment is complete. If the bubble runs to one end as the telescope is thus revolved, the vertical axis is out of adjustment and may be corrected as follows. Bring the telescope directly over a pair of opposite plate screws, and by means of these screws bring the bubble accurately to the center of the tube. Now revolve the telescope on the vertical axis as nearly as possible through 180 degrees and note the displacement of the bubble: bring the bubble one-half of the way back to the center by the screws, at one end of the bubble-bar attached to the wyes, and the remainder of the distance by the parallel plate screws. Repeat the test and adjustment until the bubble remains in the center of the tube in all positions of the telescope.

Replacing the Cross-hairs. The cross-hairs in leveling instruments may be either spider webs or platinum wire. Spider webs are better, but in selecting them care should be taken to see that they are free from dust and dampness. Probably the web of the little black spider is the most satisfactory, but the web of the common spider will give good results, especially if freshly spun. Spider webs can best be carried by winding them around a stick.

The cross-hairs are attached to the small diaphragm set at the principal focus of the object-glass. To replace the cross-hairs, carefully remove the diaphragm from the telescope tube and lay it upon a white surface with the cross-hair side upwards. It will be noticed that there are incisions upon the face of the diaphragm intended to indicate the position of the cross-hairs. Fasten one end of the spider web to the diaphragm by means of beeswax or paraffine, carefully suspending the other end of the web over the opposite incision upon the diaphragm; after the web has been properly stretched by fastening it to a match, fasten the web down as before. Repeat the operation with the other cross-hair, then replace the diaphragm in the instrument, care being taken not to break the hairs. The first adjustment may then be made.

The Dumpy-level. This instrument (see Fig. 41) differs from the Wye-level in the following points: the uprights which carry the telescope are firmly attached to the bar, and the level-tube is mounted on top of the bar. The telescope is attached firmly to the uprights so that the whole structure is rigid. Attached to one of the uprights is a projecting piece with which one end of the level is connected in such a way as to permit of a slight horizontal movement. The other end of the level-tube is fixed with two capstan-headed nuts to permit of vertical adjustment.

A clamp and slow-motion screw should be attached to the center. This, while not an absolute necessity, will, when clamped, prevent unnecessary wear on the center when the instrument is carried upon the shoulder. The telescope may be either erecting or inverting, but the latter is to be preferred.

The dumpy-level, though not as convenient in its adjustments as the Wye-level, will, nevertheless, when properly adjusted, give equally good results; while on account of its simplicity and compactness, it is not so liable to have its adjustments disturbed.

Adjustments. The adjustments of the dumpy-level are two in number and should be made in the following order:

1. To make the axis of the bubble-tube perpendicular to the vertical axis of the instrument.

CALUMET-SAG CANAL SURVEYING PARTY AT "SCHWARZ" TRIANGULATION STATION, NEAR BLUE ISLAND, SANITARY DISTRICT OF CHICAGO, ILLINOIS

Courtesy of R. Isham Randolph.

2. To make the line of collimation perpendicular to the vertical axis of the instrument.

To make the first adjustment, set up the instrument firmly in a position shaded from sun and wind. Turn the telescope over a pair of opposite plate screws, and by means of these screws bring the bubble accurately to the center of the tube. Repeat the operation over the other pair of screws, and so on alternately over each pair of screws, until the bubble remains as nearly as possible in the center of the tube for both positions of the telescope, care being taken not to swing the telescope through more than 90 degrees.

Now turn the telescope accurately over a pair of opposite plate screws and after leveling carefully, swing the telescope through 180 degrees directly over the same pair of screws. If the bubble remains in the center of the tube, the adjustment is complete. If the bubble does not remain in the center of the tube, bring it one-half way back to the center by means of the vertical capstan-headed screws at one end of the tube, and the remainder of the distance by the leveling screws. Now repeat the test and adjustment until the bubble remains in the center of the tube through all positions of the telescope.

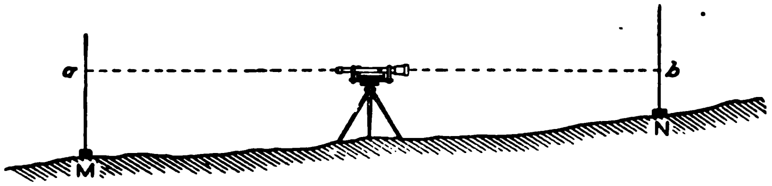


Fig. 43.

The second adjustment of the dumpy-level must be made by the "Peg Method". Select a piece of ground as nearly level as possible and lay out a straight line upon it, from 400 to 600 feet in length, driving a stake at each end and at the center. Set up the level over the center stake and after leveling carefully direct the telescope to the rod held upon N (see Fig. 43), and take the reading by the target. Now direct the telescope to the rod held at M and take the reading. The difference of these two rod readings at N and M will join the two differences of elevations, no matter how much the line of collimation is out of adjustment.

Now set up the instrument within about twenty feet of the stakes, as N, and take the rod reading; carry the rod to M and take the reading. If the difference of these last two readings is the same as before, the line of collimation is in adjustment; if not, correct nearly the whole error by means of the upper and lower capstan-headed screws attached to the diaphragm carrying the cross-hairs. Repeat the test and correction several times until the difference of elevation from both positions of the instrument agree.

It may be well to note right here that the second adjustment of the Wye-level may be made by the "Peg Method," but it is thought that the method given is the more convenient.

The Precise Spirit Level. The description of this instrument which is shown in Fig. 44 is taken from the catalogue of the makers, F. E. Brandis, Sons, & Co.

The principle underlying the construction of the instrument is that the telescope can be moved in a vertical plane about a horizontal axis by means of a micrometer screw. This construction is especially adapted to the object in view, viz: of multiplying the pointings on a mark either in the horizon of the instrument or at an angle above or below.

The superstructure consists of two uprights joined somewhat below their middle by a horizontal plate. The upper portions of the uprights are fashioned into Y's, and carry the telescope and the striding level; the lower portions are cut out so as to leave guide pieces passing outside the lower plate. A capstan-headed pivot screw passes through each guide piece at one end into small sockets in the fixed plate. Passing through the fixed plate, the micrometer screw moves between the guide pieces at the other end and abuts against a small steel surface. The fixed plate carries an index, and one of the guide pieces a corresponding scale to register the whole terms of the micrometer, and also a pointer for reading the subdivisions of the micrometer head of which there are 100.

The Gurley Binocular. The binocular hand level, as the word implies, is a hand level with a double telescope attached. It is similar to the monocular hand level in many respects, except it is provided with screw centering and focusing adjustment and can be adjusted to the different widths of the eye, avoiding all strain to the ocular muscles.

Adjustment. Follow the principles as laid down concerning the Locke hand level.

The Gurley Monocular Hand Level. This instrument is a telescope hand level, by which readings are more definitely determined on a rod at some distance than is possible with the ordinary hand level.

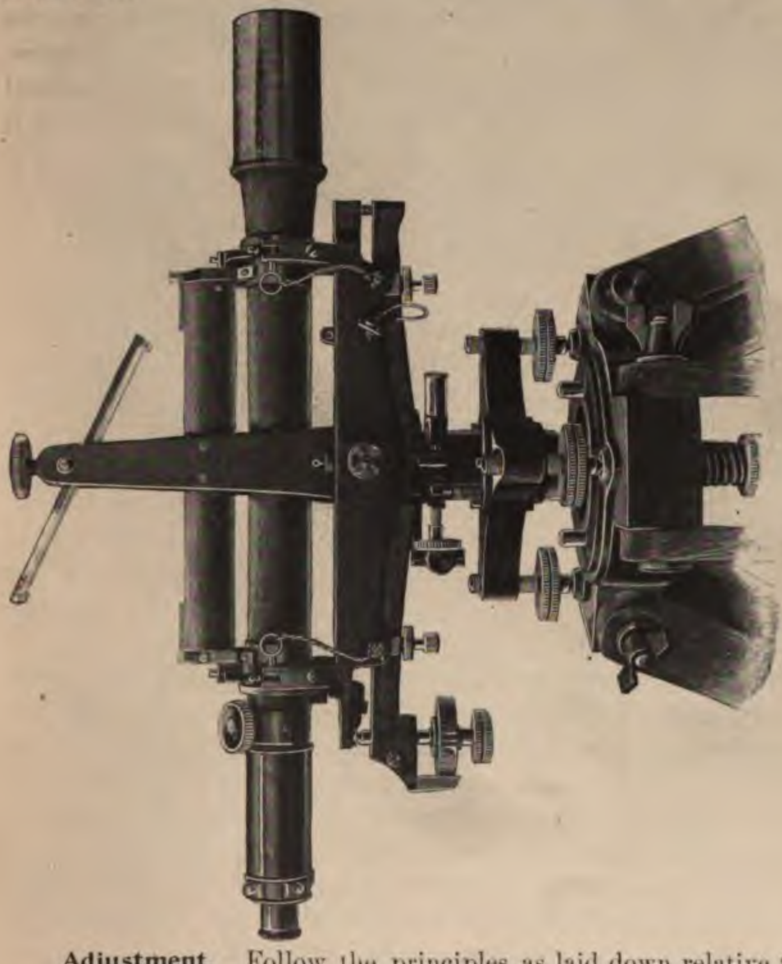


Fig. 44. Precise Spirit Level.

Adjustment. Follow the principles as laid down relative to the Locke hand level.

"Setting up" the Instrument. The term "setting up the level" means to place it in position to secure horizontal sights. To do this, plant the legs firmly in the ground at approximately equal distances apart so as to make the leveling plate horizontal. Bring the telescope directly over and in line with the two leveling screws between the plates and opposite each other. As you stand facing the instrument turn the thumb of the left hand in the direction of the motion of the bubble and turn both thumb screws towards or away from each other, being careful not to strain the level plates by having the leveling screws too tight. These screws should bear firmly upon the plates and should move with ease and smoothness, but there should be no movement of the vertical axis of the instrument. Turn the screws until the bubble appears along the graduations of the bubble tube and bring it to the middle, then turn the telescope at right angles to these two screws and over the other two. In like manner perform the same operation as before. This will cause the bubble to run away from its former position; bring the bubble accurately in the center of the tube over these screws, that is, having equal spaces on each side of the zero of the scale, then turn the telescope over the former screws and bring the bubble in the center. Do this several times until the bubble remains stationary at any angle the telescope may turn; to test this, turn the telescope half way around and see if the bubble moves; should it remain stationary, the instrument is level. The level is, with few exceptions, never placed in line (except when being adjusted under the

Fig. 45.

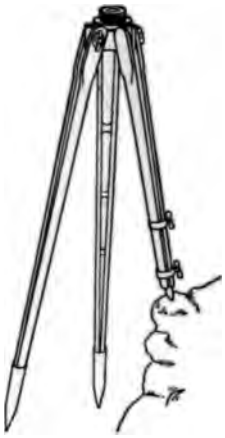


Fig. 46.

peg method). It is usually placed in some convenient spot where the greatest number of horizontal sights can be secured. As already stated, the tripod legs must be so placed as to make the plates horizontal. This will save time in bringing the bubble in its proper position. Should it be required to set up the instrument on the side of a hill, place one leg at an altitude and the other two in apparent line with each other (see Figs. 45 and 46), but where the tripod is adjustable the proper method is apparent.

After the instrument is set up and leveled, focus the eyepiece upon the wires and focus the object-glass on the rod by means of the screw placed for that purpose on the top or side of the telescope Care should be taken not to take a reading until the bubble has been carefully observed and brought in the exact center of the bubble tube. When this is completed, sight through the telescope and note the rod reading or set the target rod; again look at the bubble and see if it has moved away from its former position; if not, again sight on the rod and see if the first observation was correct. Should the intersection of the cross-hairs fail to coincide with the horizontal and vertical lines of the target or the center of the rod, the rodman is to incline the rod by the signals of the observer, until it coincides or is in line of collimation.

Care of the Instrument. This duty properly belongs to the instrument man or leveler, and the requirements should be thoroughly understood. While in the field, the instrument remains on the tripod and is carried from place to place as the work requires, but when taken any distance, such as on railway trains, street cars, etc., it should be carefully placed in the box and carried by one who is capable of giving it proper care and attention.

The instrument man being responsible for the instrument, it is natural, and perhaps best, that he should always carry the instrument. In fact, the greatest amount of precaution should be exercised in the care of the instrument, both in the field and while conveying it.

Instruments in general, the level in particular, should never be unduly exposed to the rays of the sun, as this will have a tendency to throw its various sensitive parts out of adjustment, therefore, whenever possible, place the instrument, whether it is on the tripod or not, in the shade.

The leveler should always exercise great care not to disturb the instrument after it is set up and should avoid, as much as possible, walking around it unreasonably, especially if the ground is soft, or the position of the instrument not very firm. This applies to all persons whether in the active performance of duty or not. It is frequently necessary to set up the instrument in places such as loose timber, rocks, etc., thus the importance of this care is apparent. If disturbed to any great extent it will be necessary to relevel it, and if the position of the legs of the tripod is disturbed, the entire work must be done over, because the height of the instrument will not be the same as in its former position. Should the instrument be disturbed after a turning point has been established and its elevation ascertained, it will only be necessary to take a reading on the last turning point to determine the new height of the instrument. After leveling, the instrument man should keep his hands off the instrument except for the purpose of leveling and adjusting the telescope. He should not make a practice of leaning his weight on the tripod. It is often necessary to send instruments great distances, and in so doing, in no case should it be sent by express or freight without first being properly packed and secured against breakage; because of its fine construction and sensitiveness it may get out of adjustment to such an extent as to render it impossible to readjust it for good work by any method known to the engineer, and may become worthless and beyond repair even to an instrument maker.

The student should appreciate that the care of the instrument is just as important to good work as its original excellence.

Leveling. To determine the difference in elevation between two points, both of which are visible from a single position of the instrument, set up the instrument in such a position that the rod held upon either point will be visible. Now send the rod to one of the points as at A in Fig. 48; direct the telescope upon it and take the rod reading; now direct the telescope to the rod held at B and again note the reading. Evidently the difference of the rod will give the difference in elevation of the two points.

If the points are too far apart or if the difference of elevation is too great to be determined from one setting of the instrument, intermediate points must be taken. For instance, suppose it is desired to find the difference of elevation of A and C in Fig 47, C being too far below A to permit of being read upon both points from a single position of the instrument. Set up the instrument (not necessarily on line from A to C) in some position such that the line of sight will strike the rod as near its foot as it is possible to take a reading: send the rod to some point B such that the line of sight will strike the rod near the top when extended. The difference of these rod readings will give the difference of level of A and B. Now carry the instrument to some point such that rod readings can be taken upon B and C. The difference of the rod readings upon B and C added to the difference of rod readings upon A and B will give the difference of level of A and C; proper attention being given to signs.

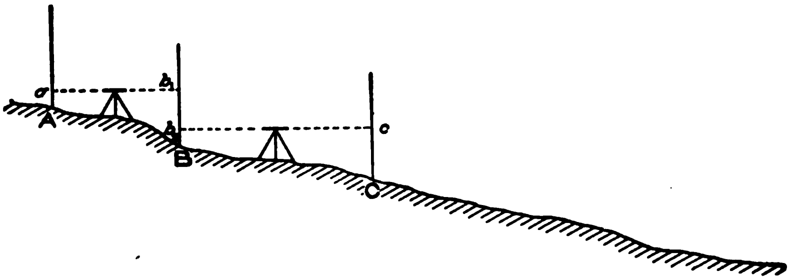


Fig. 47.

If the line of levels is very extended the above method is awkward, as some of the differences will be positive and some negative. Choose some plane called a datum plane, such that all of the points in the line of levels will lie above it.

Beginning at the point A, assume the elevation of the point above the datum plane. Read the rod held upon A, and the reading added to the assumed elevation will give the height of the cross-hairs above the datum plane, called the "height of instrument" (H.I.). Now, turn the instrument upon the point B and read the rod and it is evident that this last rod reading subtracted from the height of instrument will give the elevation of B above the datum plane. Next move the instrument beyond B, or at least where it can command a view of B and C and again sight to the rod held upon B. This last rod reading added to the elevation of B will give the new height of instrument from which if the rod reading at C is subtracted will give the elevation of C above the datum plane. Fig. 48 will make the method of procedure apparent.

Referring now to that figure, the first rod reading taken upon the point A is ordinarily called a "back-sight" and the first reading taken upon B is called a "fore-sight". There seems to be no good reason for adhering to this method of distinguishing between the rod readings and it is illogical and misleading. A back sight is not necessarily taken behind the instrument, that is, in a direction contrary to the progress of the survey, neither is a fore-sight necessarily taken in front of the instrument. It is more logical and less misleading to designate these rod readings by the terms "plus-sight" and "minus-sight".

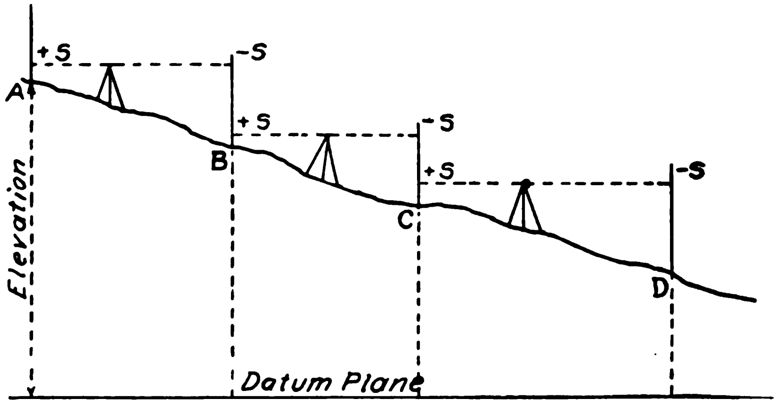


Fig. 48.

A plus-sight, therefore, is one taken upon a point of known or assumed elevation, to determine the height of instrument.

A minus-sight is one taken upon a point of unknown elevation and which, subtracted from the height of instrument, will give the required elevation.

A "bench-mark" (B.M.) is some object of a permanent character, the elevation of which, together with its location, is accurately determined for future reference and for checking the levels.

A "peg", "plug", or turning point" (T.P.), is a point used for the purpose of changing the position of the instrument. This turning point may be taken upon a bench-mark, but is oftener taken upon the top of a spike or stake driven into the ground.

If a self-reading rod is used, the instrument man will carry the notebook and record the rod readings as they are observed. The leveler should cultivate the practice of calculating the elevations of his stations as the work progresses, thereby enabling him to discern errors when they occur.

If a target rod is used upon the work, the rodman should also carry a notebook in which he should at least enter all readings upon turning points and bench-marks and check up with the instrument man at every opportunity. Under the circumstances, the instrument man is more or less dependent upon his rodman for the correct reading of the rod and when an inexperienced rodman must be employed, the self-reading rod will give the better results.

The limit of range of an ordinary leveling instrument is about 400 feet, and sights should not be taken at a greater distance.

The method of keeping the field notes for the work above outlined is given below. A level notebook especially adapted to the purpose should be procured, the notes entered on the left-hand pages, the right-hand pages being reserved for remarks, sketches, etc.

Sta.	+ S	H. I.	—S	Elev.	
A	0.650	1000.650		1000.00	⊗ N. E. cor.
B	1.250	993.140	8.760	991.890	of abutment
C	2.380	987.670	7.850	985.290	Main street
D			9.570	978.100	bridge.

It will be noticed that the algebraic sum of the plus and minus readings equals the difference of elevation of the first and last stations, and these quantities should be checked as often as possible to discover errors in addition or subtraction.

Profile Leveling. The method of profile leveling is the same in principle as above outlined, but the details of field work are a little different.

In this sort of work it is intended to determine a vertical section of the ground above a datum plane. To this end, rod readings are taken sufficiently close together that when the elevations are plotted and the points connected, the resulting irregular line will closely approximate the actual line of the surface.

Profile levels are usually run in connection with a transit or chain survey of the line, the positions of the points being first established upon railroad surveys. These points are usually 100 feet apart unless the ground is very irregular, when they may be 50 or 25 feet apart or even less, the points being indicated by stakes. Upon sewer or street work they should seldom be more than 50 feet apart and the readings should be taken with the rod held upon the ground.

Fig. 49 will illustrate the difference between profile leveling and the first system outlined, sometimes called differential leveling or "peg" leveling. Referring now to that figure A B is the datum

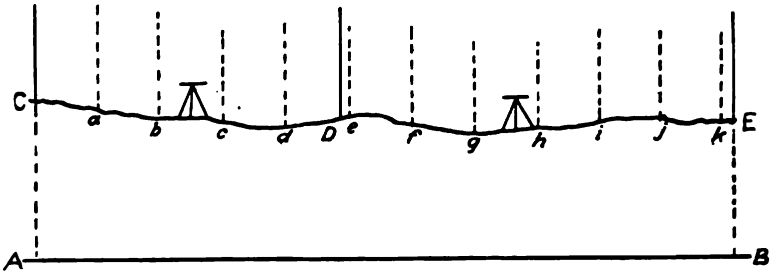


Fig. 49.

plane and the full lines at C,D, and E represent positions of the rod for turning points. Assuming the elevation of the point C, the rod is held upon it and the reading added to the elevation for the height of instrument. The rod is then carried successively to the points *a*, *b*, *c*, *d*, and each reading is in turn subtracted from the height of instrument at C, to get the elevations of these points.

The rod is then held upon the point D, the instrument moved and the plus-sight upon D added to the elevation for the new height of instrument. The rod readings upon *e*, *f*, *g*, *h*, *i*, etc., are then each subtracted from this new height of instrument for elevations.

This figure illustrates the improper use of the terms back-sight and fore-sight. The rod readings at C, *a*, and *b* are taken behind the instrument, but the rod reading at C is the only plus-sight.

The method of keeping the field notes is illustrated below.

Sta.	+S	H. I.	—S	Elev.
O.	3.25	585.70		582.45
+ 50			3.78	581.92
1			4.18	581.52
+ 50			5.06	580.64
T. P. + 62	2.64	581.49	6.85	578.85
2			3.10	578.39
+ 50			3.18	578.31
3			3.90	577.59
+ 50			4.60	576.89
4			5.25	576.24

CROSS-SECTIONING.

One of the most important problems that confronts the leveler is the setting of "slope stakes," called cross-sectioning, from which may be determined the amount of earthwork in cut or fill, and which mark the extreme limits of the operations of the construction corps in building railways, highways, sewers, canals, irrigation ditches, etc.

The problem is as follows: Given the required width of finished roadbed or channel, with proper side slopes (depending upon the kind of material), it is required to determine where these side slopes will intersect the natural surface of the ground with reference to the center line of the survey. The center line is defined by stake, carefully aligned and leveled, and a profile of it is prepared upon which the grade line is laid down, showing the

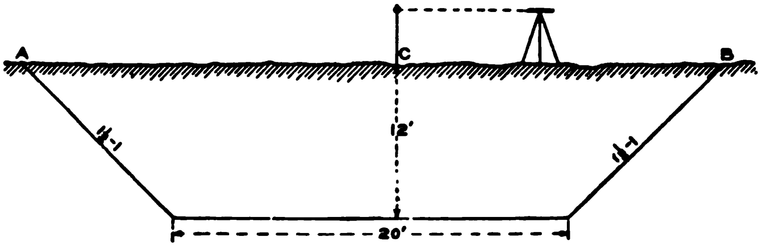


Fig. 50.

elevation of the finished roadbed or channel with reference to the natural surface of the ground.

Let us assume the ground to be level transverse to the center line. Depth of cut at center = 12 feet; side slopes 1½ feet horizontal to 1 foot vertical; width of cut at bottom = 20 feet. See Fig. 50.

Set up the instrument in some convenient position that will command a view of as much ground as possible. Hold the rod upon the ground at the center stake and note the reading. Suppose it to be 3.5 feet. Now if the ground is level, the distance from C to B is evidently 10+(12×1½) = 28 feet and the rod should again read 3.5 feet when held at B. The point A would be found in the same way.

The notes would be kept as shown below.

Sta.	Dis.	Left	Center		Right	Area	C. Yds.
175	50	+12.0 28	+12.0		+12.0 28		
176		+3.0 14.5	+6.0	7	+9.2 23.80		
176	50	+2.5 13.75	+5.0	9	+8.0 22		

The preceding example illustrates one of the simplest cases that occur in practice. Let us now take the case of a line located upon the side of a hill. See Fig. 51.

Depth to grade at center 6 feet; width at bottom 20 feet; side slopes 1½ to 1. As before, hold the rod upon the ground at C and determine the height of instrument above C. Suppose this to be 5.5 feet. Now, if the ground were level through C it would be necessary to measure to the right 10 + (6×1½) = 19 feet to the point D and the rod should read 5.5 feet. Instead it reads, say 2.8 feet. We know therefore that we have not gone out far enough by (5.5—2.8) 1½ = 4.05 feet, if the ground were level through the point D, bringing us to the point E where the rod should read 2.8 feet. Suppose it reads 2.3 feet. We must then go out 0.75 foot farther, each move bringing us closer and closer to the point B. This operation may be repeated as often as is considered necessary, but with a little experience in this sort of work the instrument man can direct the rod closely enough to the point B for all practical purposes. We then enter the notes in the second line of the record shown above.

Upon the left of the center, these operations are reversed. That is to say, we measure out 19 feet and instead of the rod reading 5.5 feet, it reads, say, 8.5 feet. We know then that we are out too far by 4.5 feet. We then move in toward the center the required distance and read the rod again, noting how much it differs from 8.5 feet, if any, and enter the final results in the notes.

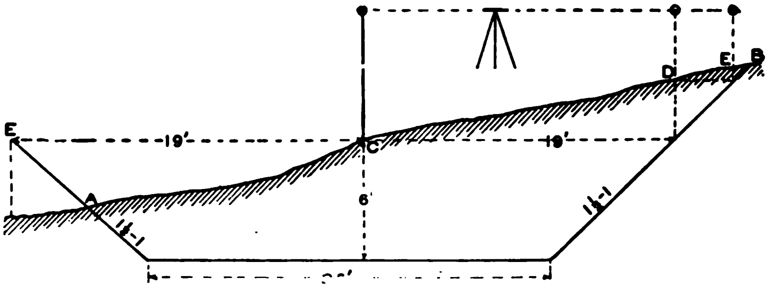


Fig. 51.

A third case is shown in Fig. 52, in which the transverse slope is not uniform. The method of procedure is the same as in the other cases, but the rod should be held at the point where the slope changes in order to find its height above grade. Enter this and the distance out in the third line of the notes.

The transverse section may be very irregular, in which case it may be necessary to take readings at several points in order to calculate the area of the sections with more exactness. At times a section will be cut partly in rock and partly in earth, forming a

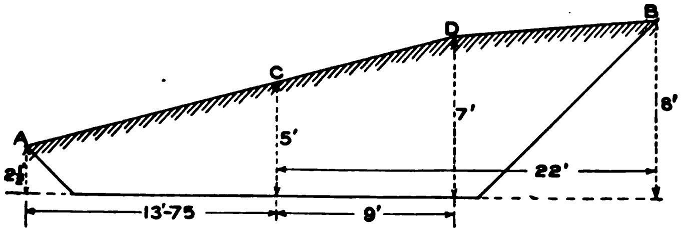


Fig. 52.

compound section. Each material will, of course, have its own proper side slope, and the depth and extent of each must be determined by soundings.

In case the section is in fill instead of in cut, the method is the same as in the preceding cases, as will be illustrated in the following examples. Let us first take a section level transversely. See Fig. 53.

In this case the finished grade is to be 9 feet above the point

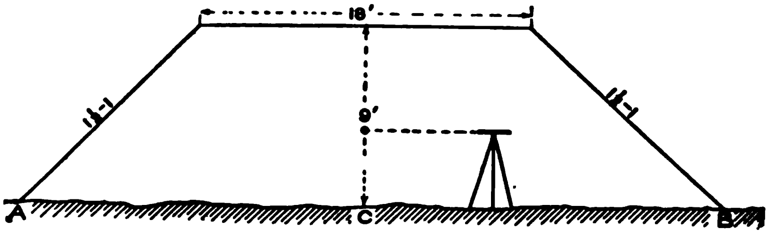


Fig. 53.

C. Hold the rod at C and suppose it reads 3.25 feet. Now since the ground is level we go out to the right and left $9+(9\times1\frac{1}{2}) = 22.5$ feet and set the stakes at A and B entering the record in the notebook as before, except that now the numerator of the fraction will be marked — instead of +.

We will next take the case where the surface of the ground has a transverse slope. See Fig. 54. Now hold the rod at the point C, and suppose it reads 9.25 feet. Now if the ground were

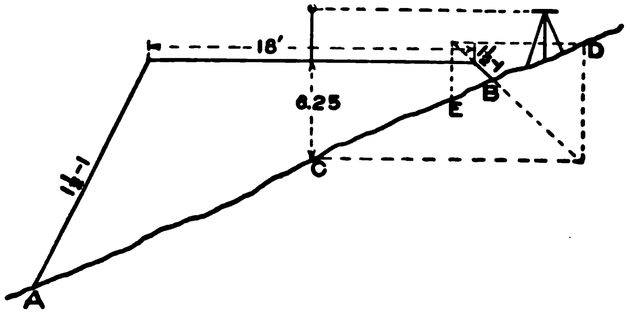


Fig. 54.

level through C we would have to go out to the right $9+(6.25\times1.5) = 18.4$ feet to some point D. But there the rod reads, say, 1.5 feet, hence we know we are out too far by $7.75\times1.5 = 11.63$ feet, bringing us back to some point as E and the rod now reads, say, 3.5 feet and we move out again $2.0\times1.5 = 3$ feet. Therefore we move back and forth until we find the point B where the computed rod reading and the actual reading agree.

Sometimes it will be found that a part of the section is in cut and a part in fill, but methods outlined will serve in any case.

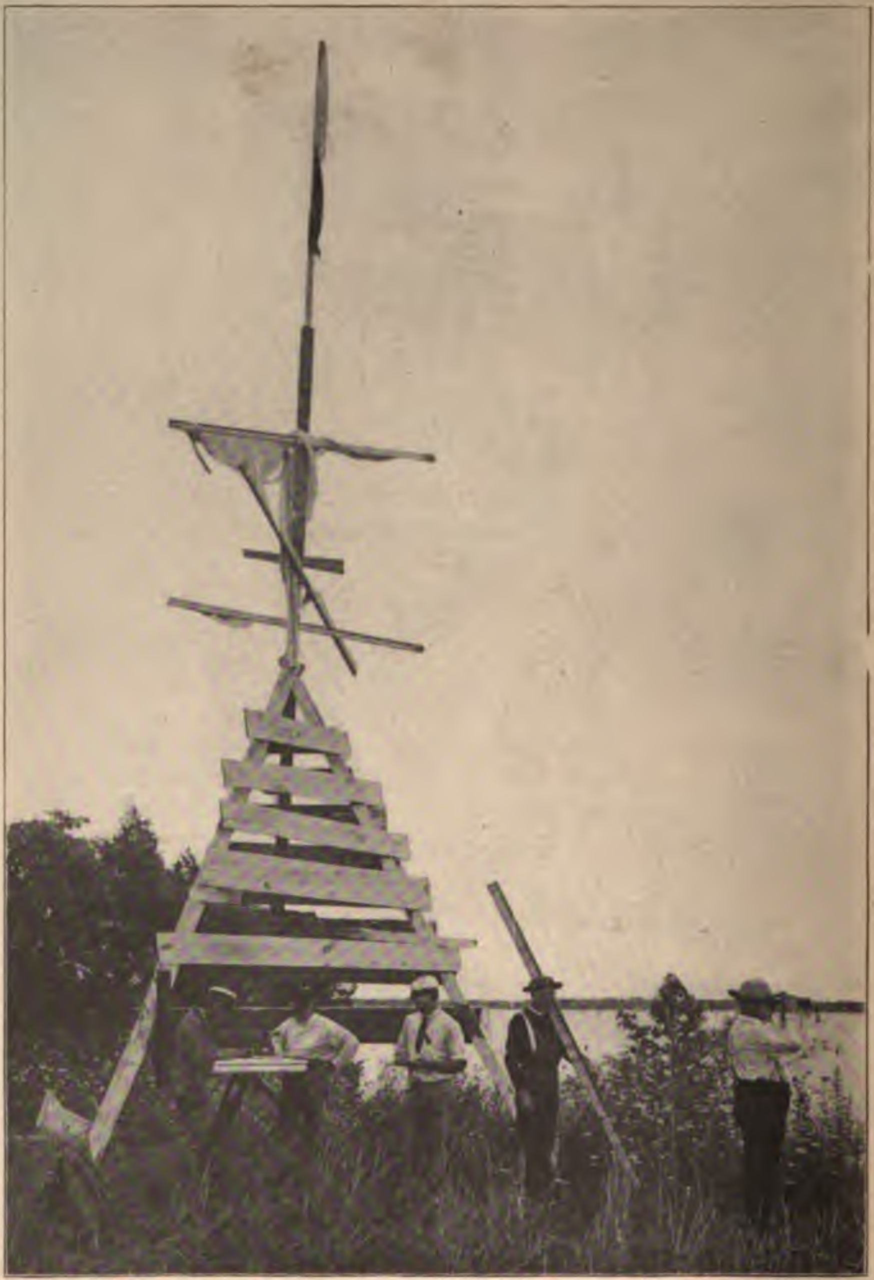
The distance between the sections longitudinally will depend upon the nature of the ground. On uniformly sloping or level ground they may be taken 100 feet apart. Over uneven ground it may be necessary to take them as closely together as 25 feet or even less. In the sections themselves, a sufficient number of rod readings should be taken that the area of the sections may be determined with reasonable accuracy.

After the field work is completed, the notes are plotted, usually upon cross-section paper, and the areas determined either with a planimeter, by Simpson's rule or some other method. These sections then divide the earthwork into a system of prismoids of which the volume must be calculated. The formula for calculating volumes is known as the Prismoidal Formula and is as follows:

$$\frac{l}{6\times27}(A+4M+B)$$

in which l = length between consecutive sections, A = one end section, B = the other end section and M = the section midway between the two. The result is given in cubic yards.

The mistake must not be made of assuming that M is a *mean* between A and B; but a theoretical section must be plotted whose dimensions are a mean between those of A and B. This often results in quite a complicated problem, and various other formulas have been devised to give sufficiently close results without the labor and time involved in the preceding. This will be treated in detail in Railroad Engineering.



COAST SURVEY PARTY STARTING TO WORK FROM A TRIANGULATION STATION

The topographer and his assistant are adjusting the instrument under the "signal;" the instrument man is at his never-ending task of putting needle-points on pencils; one of the rodmen (with telemeter rod) is waiting for instructions to set out, and the other is picking up other "signals" with the glasses.

THE NEW
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TOPOGRAPHER OF U. S. GEOLOGICAL SURVEY ON WAY TO WORK IN CALIFORNIA

PLANE SURVEYING.

PART II.

The **meridian plane** of any place upon the earth's surface is a great circle passing through the zenith of the place and the poles of the earth. A true meridian is, therefore, a line lying in this plane, and would, if produced, pass through the poles.

The magnetic meridian plane would in the same way be defined by the zenith and the magnetic pole of the earth; but since this pole is not fixed in position, the magnetic meridian is defined as the direction of the line indicated by the position of the magnetic needle.

At a few places upon the surface of the earth, the true meridian and the magnetic meridian coincide *at times*, but for the most part they differ in direction by an ever varying quantity. The angle at any place between the true meridian and the meridian as defined by the magnetic needle, is called the **magnetic declination** for that place. If the direction of the magnetic meridian were constant, or if the changes followed any particular law, it would be a comparatively simple matter to determine the declination for any time or place. The variations occurring are of three principal kinds—diurnal, annual, and secular, the last being the most important.

Diurnal Variation. On continuing observations of the direction of the needle throughout the day, it will be found that the north end of the needle will move in one direction from about 8 A. M. until shortly after noon, and then gradually return to its former position.

Annual Variation. If observations be continued throughout the year, it will be found that the diurnal changes vary with the seasons, being greater in summer than in winter.

Secular Variation. If accurate observations on the declination of the needle, in the same place, are continued over a number of years, it will be found that there is a continual and comparatively constant increase or decrease of the declination, continuing in the same direction over a long period of years.

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Besides the above, the declination is subject to variations more or less irregular, due to local conditions, lunar perturbations, sun spots, magnetic storms, etc.

The declination in any part of the United States may be approximately determined by consulting the chart issued from time to time by the United States Coast and Geodetic Survey. (See chart, page 132.) Upon this chart all points at which the needle points to the true north are connected by lines, called **agonic lines** or **lines of no declination.** Lines are also drawn connecting points of the same declination, called **isogonic lines.**

The isogonic curves or lines of equal magnetic declination (variation of compass) are drawn for each degree, a + sign indicating West declination, a — sign indicating East declination.

The magnetic needle will point due North at all places through which the agonic or zero line passes, as indicated on the chart.

Before undertaking an extensive or important survey, it is the first duty of the surveyor to determine accurately his declination. This is best done by laying out a true meridian upon the ground and comparing its direction with that indicated by the needle. Before describing the methods of laying out a true meridian, it will be best to describe the compass.

THE COMPASS.

Construction. The surveyor's compass consists primarily of a circular brass box, carrying, upon a pivot in its center, a strongly magnetized needle (see Fig. 56). The inside edge of the box on a level with the needle, is usually graduated to half degrees, and smaller intervals may be "estimated." Two points diametrically opposite each other are marked 0°, and form the north and south ends of the box, the *south* end being indicated by the letter S, and the *north* end either by the letter N or by a fleur-de-lis or other striking figure. The divisions extend through 90° upon both sides of these points, to the east and west points marked respectively E and W. The east side of the box, however, is on the left as the observer faces the north end; this is because the needle remains stationary while the box revolves around it. The divided circle is sometimes movable, being fitted with a clamp and tangent-screw for setting off the declination of the needle.

The **magnetic needle** is the most essential part of the compass. It consists of a slender bar of steel, usually five or six inches long, strongly magnetized, and balanced on a pivot so that it may turn freely and thus continue to point in the same direction however much the box carrying the pivot may be turned around. To this end the pivot should be of the hardest steel, ground to a very fine point, or, better still, of iridium; and the center of the needle resting upon the pivot should be fitted with a cap of agate or other hard substance.

To distinguish the ends of the needle, the north end is usually cut into a more ornamental form than the south end, or the latter end may be recognized by its carrying a coil of wire to balance the "dip."

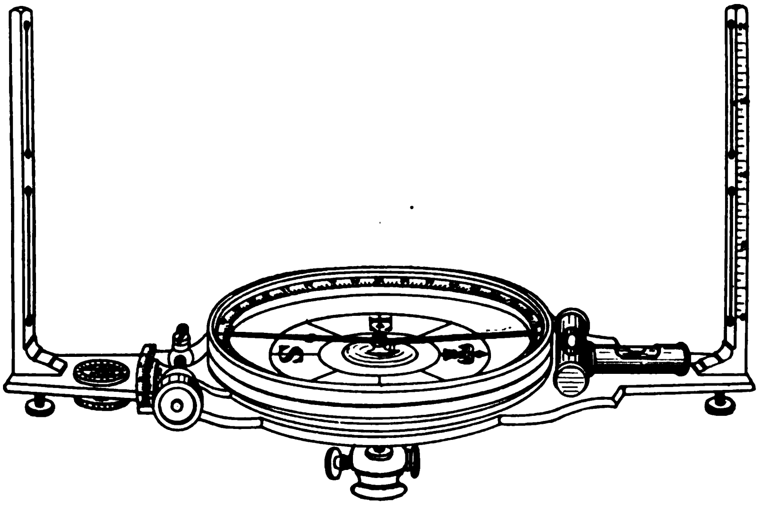


Fig. 56.

Intensity of directive force and sensitiveness are the chief requisites in a magnetic needle, and nothing is gained by making a needle over five inches in length. Indeed, longer needles are liable to have their magnetic properties impaired by polarization. The needle should not come to rest too quickly. Its sensitiveness is indicated by the number of vibrations that it makes in a small space before coming to rest. Should it come to rest quickly or be sluggish in movement, it indicates either that the magnetization is weak or that there is undue friction between needle and pivot.

The under side of the box should be fitted with a screw which, engaging a lever upon the inside of the box, will serve to lift the needle off the pivot when the instrument is carried about.

The **sights** form the next most important feature of the compass. They consist of two brass uprights, with a narrow slit in each, terminated at intervals by circular apertures. They are mounted directly upon the compass-box; or the bottom of the box may be extended at each end in the form of a plate, and the sights attached at the ends of the plates. However mounted, the sights should have their slits in line directly over the north and south points of the divided circle. The right and left edges, respectively, of the sights, may have an eye-piece and a series of graduations, by which angles of elevation and depression for a range of about twenty degrees each way can be taken with considerable accuracy. This device is called a **tangent scale,** so called because of the distance of the engraved lines from the 0° line being tangents (with a radius equal to the distance between the sights) of the angles corresponding to the numbers of the lines.

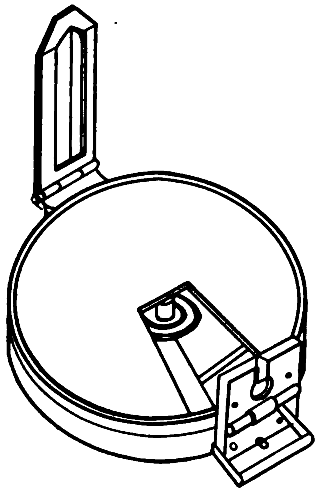


Fig. 57.

The spirit levels may be placed at right angles to each other in the bottom of the compass-box, or mounted in the same way upon the plate.

The compass is usually fitted to a spindle made slightly conical, which has on its lower end a ball turned perfectly spherical, confined in a socket by a pressure so light that the ball can be moved in any direction in leveling the instrument. The ball is placed either in the brass head of a Jacob staff, or, better, in the top casting of a tripod.

A plumb-bob should be provided with the instrument to center it over a stake.

A telescope is sometimes provided, to be attached to one of the vertical sights, for the purpose of more clearly defining the line of sight. The compass is, however, so inaccurate that it would seem to be an unnecessary refinement.

Prismatic Compass. This is a form of compass used in general where merely ordinary work is required. It is about 3 inches in diameter with a floating metal dial (see Fig. 57), and is provided with folding sights and prism. By means of the latter it may be read while being pointed. This is especially useful when the instrument is held in the hand. Although it can be mounted on a Jacob staff, it is usually held in the hand and carried in the observer's pocket.

Adjustment. *To Adjust the Levels.* First bring the bubbles to the middle of the tube by the pressure of the hand on different parts of the plate, and then turn the instrument half-way round. If the bubbles remain in the middle of the tubes, the tubes are in adjustment. If the bubbles do not remain in the middle, raise or lower one end of the tube to correct one-half the error. Relevel the instrument, again test, and apply the correction as before. Continue the operation until the levels are in perfect adjustment.

To Adjust the Needle to the "Dip." While the compass is still in a perfectly level condition, see if the needle is in a horizontal plane. Should this not be the case, move the small coil of wire towards the high end until the needle swings horizontally.

To Adjust the Sight-Vanes. Observe through the slits a fine hair or thread made exactly vertical by a plummet. Should the hair appear on the side of the slit, the sight-vane must be adjusted by filing its under surface on the side that seems the higher.

To Adjust the Needle. Having the eye nearly in the same plane with the graduated rim of the compass-box, bring one end of the needle in line with any prominent graduation mark in the circle, as, for instance, the zero or the 90-degree mark, and notice if the other end corresponds with the same degree upon the opposite side; if it does, the needle is said to "cut" opposite degrees; if not, bend the center pin, until the ends of the needle are brought into line with the opposite degrees.

Then, holding the needle in the same position, turn the instrument half-way round, and note whether the needle now cuts opposite degrees; if not, correct one-half the error by bending the needle, and the other half by bending the center pin. The operation of testing and correcting should be repeated until perfect reversion is secured in the first position. This being obtained, the operation should be tried on another quarter of the circle; if any error is found, the correction must be made in the center pin only, the needle being already straightened by the previous operation. When the needle is again made to cut, the test should be tried in the other quarters of the circle, and the correction made in the same manner, until the error is entirely removed and the needle will reverse at every point of the graduated circle.

Use. In the operation of locating points, and therefore lines, by angle-measuring instruments, two operations are necessary:—(1) to measure the angle at the instrument between some given line and the line passing through the given point; (2) to measure the distance from the instrument to the given point. For the first operation two types of instrument are in general use — the compass and the transit. For the compass, the line of reference from which all angles are measured is a meridian, and the angular deviation from this line is called the **bearing.** The bearing and length of a line are collectively named the **course.** The compass, therefore, measures bearings directly and angles indirectly.

To Determine the Bearing of One Point from Another. "Set up" the compass over one of the points, and level carefully. Turn the sight-vanes in the direction of the second point, *with the north end of the plate ahead.* Hold a rod upon the second point, and cover it with the slits in the sight-vanes. Now lower the needle upon the pivot, being sure that the instrument is still level; allow it to come to rest, and read the bearing.

To Survey a Series of Lines with the Compass. "Set up" the compass over the point A, with the north end of the plate ahead (Fig. 58); and after leveling, turn the sight-vanes to cover a rod held upon the point B. Now send out the tape in the direction of B, and, sighting through the slits, signal the head tapeman into line. Continue this until the point B is reached. Now read and record the bearing and the length of the line. Take up the instrument, and carry it to B. Set it up over B, with the north end ahead, that is, pointing in the direction of the survey. Level, and turn the south end so as to cover a rod held upon the point A.

Read the bearing as a check upon the former one, but reversed in direction; *i. e.*, if the bearing from A to B was north by east, the bearing from B to A will be south by west. If the direct and reversed bearings check, turn the north end of the compass to cover a rod held upon C. Read the bearing, measure B C, take the instrument to C, and proceed as before.

If at any station, such as C, the direct and reversed bearings do not agree, take the instrument back to B and again take the bearing of B C. If they still disagree it indicates local attraction at C. Take the instrument to D and take the bearing of D C, comparing it with the bearing of C D. If these disagree, record the bearings of B C and D C as well as those of C B and C D. The latter should check the former, since the local attraction at C will affect both lines equally; and the correct angle between the lines can be computed.

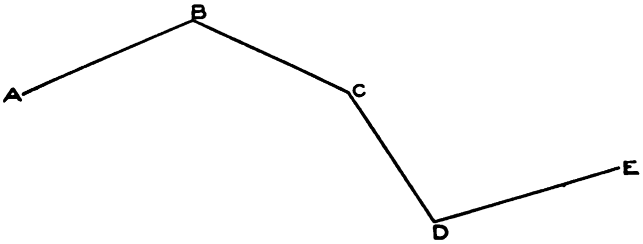


Fig. 58.

Locating a series of lines with certain lengths and bearings is essentially the same as above, except that after the compass has been turned in the proper direction, the stations must be brought into proper line.

Here it may be well to remark upon the proper method of reading and recording bearings. Always read the north or south end of the plate first; *i. e.*, if a line has a bearing 35° east of north, it should be read and recorded N 35° E. If the bearing is 90° east or west of north or south, record the bearing as E or W.

The Gunter's chain is always used in land surveys made with the compass, and deeds and records of such surveys are based upon the Gunter's chain as the unit.

Hints Regarding the Use of the Compass. Sometimes, as when the line of which the bearing is required consists of a fence, etc., the compass cannot be set upon the line. In such a case measure off equal distances at right angles to the line, and find the bearing of the parallel line; the length should be measured upon the line itself. In other cases it may be more convenient to set the compass or rod "in line" upon the line produced, or upon some intermediate point of the line.

It is more important to have the compass level, crosswise of the sights, than parallel with them.

Avoid reading the bearing from the wrong number of the two between which the needle points, as for instance 35° for 25°.

Check the vibrations of the needle by gently raising it off the pivot and lowering it again by means of the screw on the under side of the box.

If the needle is slow in starting, smartly tap the compass to destroy the effect of any possible adhesion to the pivot or friction of dust upon it.

Avoid holding the pins, axe, or any other body of iron, in close proximity to the needle.

Should the needle adhere to the glass after the latter has been dusted with a handkerchief or has been carried so as to rub against the clothes, the trouble is due to the glass being thereby charged with electricity and may be obviated by moistening the finger and applying it to the glass.

RELOCATION.

Suppose it is required to relocate a line, no trace of the old survey being at hand except the given line. Now, between the date of the old survey and the present, the declination of the needle has changed several degrees. The first duty of the surveyor is to consider this question very carefully, and to ascertain the probable amount of change in the magnetic needle. Suppose the result of his inquiry leads to N 38° 15′ E as the bearing. Starting at corner A, Fig. 59, the surveyor runs a random line AS on the bearing N 38° 15′ E, and measures along this line a distance of 32 chains, or 2,112 feet, to point S. On arriving at S, the surveyor proceeds to look over the ground on both sides of this point for a lost corner, which is described in the old record as a monument, stump, or some other well-defined mark. If, after diligent search, no trace of this mark can be found, nothing further can be done from the data at hand. However, should the mark be found at *m*, a perpendicular is dropped upon the line AS, and its length is measured, as is also the distance *n*S. It is now evident that the distance A*n* becomes known. From the right triangle, the angle *n*A*m* can be computed, and the present magnetic bearing of A*m* can be determined.

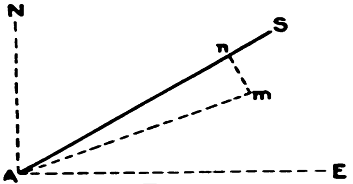


Fig. 59.

For example, suppose that *mn* is found to be 37.4 feet, while A*n* is 2,110.5 feet, then tan. $nAm = \frac{mn}{An} = 0.01772$, whence $nAm = 1^\circ\ 01'$, and the present magnetic bearing of A*m* is N 39° 16′ E. The distance $Am = \frac{2,110.5}{\cos.\ 1^\circ\ 01'} = 2,110.84$ feet. This indicates that the present work is correct, and that the old survey was in error by 1.16 feet. As there is a principle of law that establishes corners and monuments, resurveys must control; therefore the new record of the line A*m* is N 39° 16′ E, 2,110.84 feet. Intermediate points of the line A*m* may now be established from the starting point A, running it out with the new bearing.

EXAMPLE FOR PRACTICE.

Compute the distance and bearing of two points which are not intervisible. Call the line GH. A line is run approximately near H, from the known corner G to a point A which is visible to H; the bearing and length of this line being N 42° 15′ E, 714.5 feet; AH being N 1° 08′ E, 210.5 feet.

Ans. N 33° 14′ E, 883.24 feet.

To Find the Bearing of One Line to Another. Suppose, in Fig. 60, that of the tract of land therein described there has been prepared a rough plot upon which the angles, bearings, and distances as taken from the field book are figured. In order to find the bearing of one line to another, add together the interior angles formed at all the corners; call their sums *a*; multiply the number of the sides by 180°; from the product subtract 360°. If the remainder is equal to *a*, this is proof that the angles have been accurately measured. This, however, will rarely if ever occur;

there will always be some discrepancy, but if the field work has been performed with reasonable care the discrepancy will not exceed two minutes for each angle. In this case divide it, in equal parts, among all the angles, adding or subtracting, as the case may be, until it amounts to less than one minute for each angle, when it may be entirely disregarded in common farm surveys.

The corrected angles may now be marked on the plot in ink, and the penciled figures erased. We shall suppose the corrected ones to be as shown in Fig. 60. Next, by means of these corrected angles, correct the bearings also.

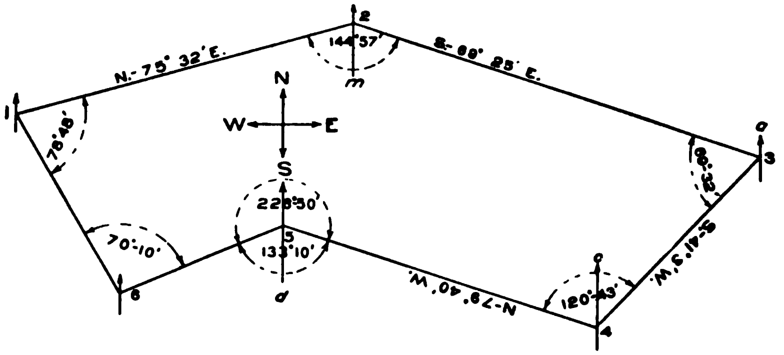


Fig. 60.

Select some side, the longer the better, from two ends of which the bearing and the reverse bearing agree, thus showing that the bearing was probably not influenced by local attraction. Let side 2 be the one so selected; assume its bearing N 75° 32′ E, as taken on the ground, to be correct; through either end of it, say at its farther end 2, draw a short meridian line, parallel to which draw others through every corner.

Now, having the bearing of side 2, N 75° 32′ E, and requiring that of side 3, it is plain that the reverse bearing from corner 2 is S 75° 32′ W, and that therefore the angle 1 2 *m* is 75° 32′. Therefore, if we take 75° 32′ from the entire corrected angle 1 2 3, or 144° 57′, the remainder 69° 25′ will be the angle *m* 2 3; consequently the bearing of side 3 must be S 69° 25′ E. For finding the bearing of side 4, we now have the angle 2 3 *a* of the reverse bearing of side 3, also equal to 69° 25′, and if we add this to the entire corrected angle 2 3 4, or to 69° 32′ we have the angle a 3 4 = 69° 25′ + 69° 32′ = 138° 57′, which, taken from 180°, leaves the angle b 3 4 = 41° 3′; consequently the bearing of side 4 must be S 41° 3′ W.

For the bearing of side 5, we now have the angle 3 4 c = 41° 3′, which, taken from the corrected angle 3 4 5, or 120° 43′, leaves the angle c 4 5 = 79° 40′, consequently the bearing of side 5 must be N 79° 40′ W. At corner 5, for the bearing of side 6, we have the angle 4 5 d = 79° 40′, which, taken from 133° 10′, leaves the angle d 5 6 = 53° 30′; consequently the bearing of side 6 must be S 53° 30′ W; and so with each of the sides. Nothing but careful observation is necessary to see how the several angles are to be employed at each corner.

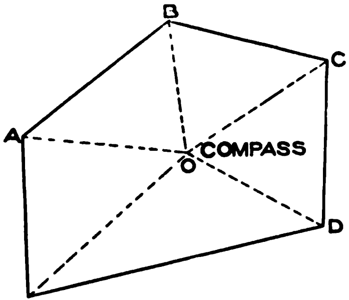


Fig. 61.

FARM SURVEYING

Method of Progression. Farm surveying with the compass does not differ in any essential particular from the methods outlined for surveying a series of lines. If the boundary lines are irregular, it will be necessary to measure offsets at proper intervals, that the included area may be calculated. The method above described is known as the method of progression.

Method of Radiation. The method of radiation consists in setting up the instrument at some point inside or outside the field, from which all the corners are visible and accessible, and then measuring the bearing and lengths of the lines to these corners. Fig. 61 illustrates the method. Set up the compass at the point O, and take the bearings and lengths of the lines O A. O B, O C, O D, and O E.

Method of Intersections. Lay off a base-line of convenient length inside or outside the field, from which all the corners are visible. Set up the compass at one end of the base-line, and take the bearings from it to each corner in succession. Remove the compass to the other end of the base-line, and take the bearings from it to each corner in succession. Take the bearing and length of the base-line. Now, when these bearings and lengths are plotted, the intersections of the lines will define the corners.

Proofs of Accuracy. When the survey of a field is plotted, if the end of the last course meets the starting point, it proves the work, and the survey is then said to "close." Errors of closure may be due either to incorrect lengths of lines or to incorrect bearings, or to both.

Diagonal lines running from corner to corner of a field may be measured and their bearings taken. When these are plotted, their meeting the points to which they were measured proves the accuracy of the work.

Finally, the accuracy of the work may be tested by calculating the "latitudes and departures" of all the courses. If their algebraic sum is equal to zero, the work is correct. A check upon the bearings may be had by calculating the "deflection angles" between the courses. If their sum is equal to 360 degrees, the bearings are correct. This, however, will seldom be the case. A certain amount of error is permissible, depending upon the nature and importance of the work.

Field Notes. The field notes may be recorded in various ways, the object being to make them clear and full.

1. The surveyor may make, in the field book, a rough sketch of the survey by eye, and note on the lines their bearings and lengths. If a protractor and scale are available, the actual bearings and lengths of the lines may be plotted in the notebooks, as well as offsets, etc.

2. Draw a straight line *up* the page of the notebook, and record on it the bearings and lengths of the lines. Offsets, tie-lines, etc., can be plotted in their proper positions.

3. Write the stations, bearings, and distances in three columns. This method has the advantage, when applied to farm surveying, of being convenient for use in the subsequent calculation of contents, but does not give facilities for noting effects. It is illustrated as follows:

STATIONS.	BEARINGS.	DISTANCES.
0	N. 32° E.	16.82
1	S. 36° E.	18.90
3	S. 27½° W.	7.85
4	S. 16° W.	15.30

Notice that distances are given in Gunter's chains, and in calculating content the result will be given in square chains, which can be reduced to acres by pointing off one decimal place.

To Change Bearings. In certain kinds of work with the compass, it is convenient to assume one of the lines as a meridian, and it then becomes necessary to change the bearings of all of the other lines to conform with the assumed meridian. This case is best illustrated by an example.

The bearings of the sides of a field are here shown: Suppose now that the first course is assumed as a meridian, that is, that its bearing is due north and south. Required the bearings of the remaining courses.

STATIONS.	BEARINGS.	DISTANCES.
1	N. 35° E.	2.70
2	N. 83½° E.	1.29
3	S. 57° E.	2.22
4	S. 34¼° W.	3.55
5	N. 56½° W.	3.23

Since the courses are changed to the west by 35°, the new bearing of course 2 will be N 48½° E. Of course 3 it will be $57° + 35° = 92°$, or the new bearing will be N 88° E. Of course 4 it will be $34\frac{1}{4}° - 35°$, or ¾° in the next quadrant, or the bearing will be S ¾° E. Of course 5 it will be $56\frac{1}{2}° + 35° = 91\frac{1}{2}°$, or the bearing will be S 88½° W.

EXAMPLE FOR PRACTICE.

The bearings of a series of courses are given as follows: The bearing of the first course is changed to due north and south.

It is required to determine the bearings of all the courses, due to this change. Find bearings and plot the lines.

Ans. Course 2 = N 62¼° E; 3 = N 9° W; 4 = N 68° W.

STATIONS.	BEARINGS.	DISTANCES.
1	S. 21° W.	12.41
2	N. 83¼° E.	5.86
3	N. 12° E.	8.25
4	N. 47° W.	4.24

Latitudes and Departures. The **latitude** of a point is its distance north or south of some line taken as a *parallel of latitude*, or line running east and west.

The **longitude** of a point is its distance east or west of some line taken as a *meridian*, or line running north and south.

The distance that one end of a line is north or south of the other end is the "Difference of Latitude" of the two ends of the line, and is called its **northing** or **southing,** or its **latitude.**

The distance that one end of a line is east or west of the other end is the "Difference of Longitude" of the two ends of the line, and is called its **easting** or **westing,** or its **departure.**

The terms **Latitude Difference** and **Longitude Difference** have of late come into quite general favor; but while they are perhaps more explicit, they are certainly cumbersome, and the older terms will be adhered to in what follows.

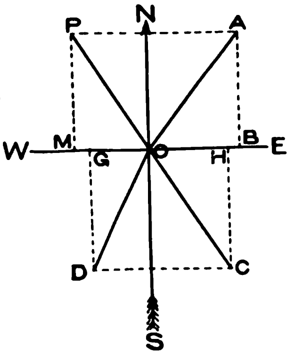


Fig. 62.

In Fig. 62, N S represents a meridian, and E W a parallel of latitude. If we take the line O A, its bearing as given by the compass is the angle NOA. The latitude or northing of the point A is therefore A B = O A cos NOA. Its departure or easting is O B = O A sin NOA.

To find the *latitude* of a course, multiply the length of the course by the natural *cosine* of the bearing; and to find the *departure* of any course, multiply the length of the course by the natural *sine* of the bearing.

If the course be northerly, the latitude will be north, and will be designated by the sign +, or plus; if the course be southerly, the latitude will be south, and will be designated by the sign —, or minus.

If the course be easterly, the departure will be east, and will be designated by the sign +, or plus; if the course be westerly, the departure will be west, and will be designated by the sign —, minus.

Thus in the figure, OA is of plus latitude and plus departure; OP is of plus latitude and minus departure; OD is of minus latitude and minus departure; and OC is of minus latitude and plus departure.

For calculating latitudes and departures, a set of traverse tables may be procured; but a table of natural functions will be satisfactory, though possibly less convenient.

Testing a Survey by Latitudes and Departures. It is evident that after the surveyor has gone completely round a field or farm, measuring all the lengths and bearings, returning to the starting point, he has gone as far north as south, and as far east as west. In other words, if the work has been done correctly, the algebraic sum of the latitudes must equal zero, and the algebraic sum of the departures must equal zero. This condition, however, will seldom be attained, and it becomes necessary to decide how much error may be permitted without necessitating another survey. This will depend upon the nature of the work and its importance, and a surveyor will soon determine for himself his factor of error, depending partly upon his instrument, partly upon personal skill, for ordinary cases. If it is necessary to depend upon a "green" hand to carry the tape or chain, this may prove a fruitful source of error.

We shall now proceed to calculate the latitudes and departures of the survey as given below. Arrange the diagram as below with seven columns:

STATIONS.	BEARINGS.	DISTANCES.	LATITUDES.		DEPARTURES.	
			N.	S.	E.	W.
1	S. 21° W.	12.41	.....	11.591	.....	4.443
2	N. 83¼° E.	5.86	0.691	......	5.819	.....
3	N. 12° E.	8.25	8.069	......	1.716	.....
4	N. 47° W.	4.24	2.892	......	.....	3.104
		30.76	11.652	11.591	7.535	7.547

The cosine of the bearing of course 1 is 0.934.12.41=11.591 — Latitude.
The sine of the bearing of course 1 is 0.358.12.41= 4.443 - Departure.
The cosine of the bearing of course 2 is 0.118.5.86 = 0.691 + Latitude.
The sine of the bearing of course 2 is 0.993.5.86 = 5.819 + Departure.
The cosine of the bearing of course 3 is 0.978.8.25 = 8.069 + Latitude.
The sine of the bearing of course 3 is 0.208.8.25 = 1.716 + Departure.
The cosine of the bearing of course 4 is 0.682.4.24 = 2.892 — Latitude.
The sine of the bearing of course 4 is 0.732.4.24 = 3.104 — Departure.

The latitudes fail to balance by 0.061 chains, and the departures by 0.012 chains. The error of "closure" of the survey is therefore

$E = \sqrt{.061^2 - .012^2} = 0.062 +$ chains, or approximately 4.09 feet. This sum may be divided up among the courses in proportion to the length, or the bearings may be corrected, or partly one and partly the other, as will hereafter be explained.

Balancing the Survey. Before proceeding to the calculation of the content of a field or farm, the survey must be balanced; that is, the latitudes and departures must be corrected so that their sums shall be equal, or shall balance. As to whether the bearings or lengths shall be corrected, will depend somewhat upon the conditions under which the survey was made. If the surveyor has reason to think that the error is entirely in the bearing of one or more, or even of all of the courses, the corrections may be made accordingly. If, on the other hand, one or more of the courses were measured over difficult ground, it may be presumed that the error occurred in those lines. If, however, there is no reason to believe that one course is in error more than another, the differences may be distributed among the courses in proportion to their length, according to the following proportions:

As the length of any course is to the sum of the lengths of all the courses, so is the correction of the latitude of that course to the total error in latitude of all the courses.

As the length of any course is to the sum of the lengths of all the courses, so is the correction of the departure of that course to the total error in departure of all the courses.

The practical application of these proportions to balancing a survey will be illustrated from the preceding problem:

For course 1 . . 12.41 : 30.76 :: x : 0.061 . . . . x .0246, correction for latitude.
For course 2 . 5.86 : 30.76 :: x : 0.061 . x .0116, correction for latitude.

PLANE-TABLE ASSISTANT TO SURVEYING PARTY OF THE U. S. GEOLOGICAL SURVEY, ON WAY TO WORK IN CALIFORNIA

For course 3.... $8.25 : 30.76 :: x : 0.061 \ldots . x = .0164$, correction for latitude.
For course 4.... $4.24 : 30.76 :: x : 0.061 \ldots . x = .0084$, correction for latitude.

Since the sum of the north latitudes is the greater, the corrections will be subracted from them and added to the south latitudes. That is to say, the correction for course 1 will be added to 11.591, the result being 11.6156. The correction for course 2 will be subtracted from 0.691: that for course 3 will be subtracted from 8.069: and so on.

For course 1...$12.41 : 30.76 :: x : 0.012 \ldots x = .0048$, correction for departure.
For course 2... $5.86 : 30.76 :: x : 0.012 \ldots x = .0023$, correction for departure.
For course 3.... $8.25 : 30.76 :: x : 0.012 \ldots x = .0032$, correction for departure.
For course 4.... $4.24 : 30.76 :: x : 0.012 \ldots x = .0017$, correction for departure.

The corrections are to be subtracted in this case from the west departure and added to the east departure.

In this example, the errors are small, but often they will be so large as to raise doubt as to the accuracy of the survey. In such a case, go carefully over all the computations, and, if the error is still too large, check the exterior angles of the figure (their sums should equal 360°), and if necessary repeat the survey. Having corrected the latitudes and departures, the corrected bearings of the courses may be deduced from the trigonometric ratio:

$$\text{Tan. bearing} = \frac{\text{corrected departure}}{\text{corrected latitude}}.$$

Calculating the Content. After a field has been surveyed, its content may be calculated by dividing it up into triangles, trapezoids, etc., calculating the various contents, and adding them together. This, however, is at best a cumbersome method, involving much work of calculation and great chance of error. The method of latitudes and departures is at once simple, easily applied, and easily checked.

Before proceeding to develop a formula for this method, it will be necessary to illustrate and define certain terms.

Draw a line, as N S (Fig. 63), through the extreme east or west corner of the field for a meridian. From the definitions previously given, the difference of longitude of the two ends of a line is the *departure* of the line. I B is therefore the departure of the line A B. The departure of the line B C is L C; that of E F is S F; and that of A F is O Q.

The perpendicular distance of each station from the given meridian is the *longitude of that station*, plus if east, minus if west. Thus the longitude of A is zero; that of B is I B; that of C is I B + L C; that of E is O Q + F S; and that of F is O Q = ZS — FS.

The difference of latitude of the two ends of a line is called the *latitude* of the line. Thus the latitude of A B is A I; that of B C is B L; that of E F is E S.

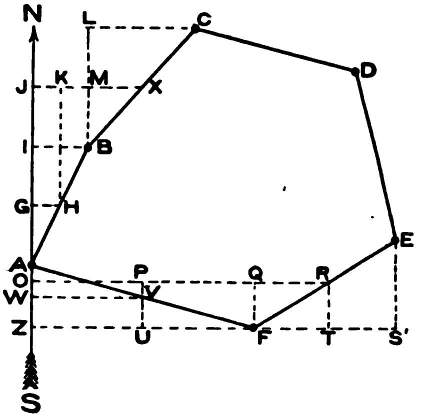


Fig. 63.

The distance of the middle of any side of a field from the meridian is called the *longitude of that side*. Thus the longitude of the side A B is G H; that of B C is J X = G H + K M + MX; and that of A F is WV = OR — QR — QP, the minus signs being used in this instance because the lines E F and A F bear to the west. An analysis of W V will show that it equals O R (longitude of preceding course) + [— R Q (one-half departure of preceding course)] + [– QP (one-half departure of the course itself)].

To avoid fractional quantities, double the preceding expressions and then deduce a general rule for finding **double longitudes.**

The double longitude of the first course equals the departure of that course. The double longitude of the second course equals the double longitude of the first course, plus the departure of the first course, plus the departure of the second course.

The double longitude of any course equals the double longitude of the preceding course, plus the departure of the preceding course, plus the departure of the course itself.

We shall now proceed to deduce a rule for determining areas by double longitudes and departures, and shall first take a three-sided field, as in Fig. 64.

Drawing a line through the most westerly corner A, we see that the area of the field will be the difference between the area of the trapezoid D B C M and the combined area of the triangles D B A and A C M. The double area of the triangle D B A is the product of D B by D A, or the double longitude of A B by the latitude of A B. The resulting product will be north or *plus*. The double area of the trapezoid D B C M is the product of (D B + M C) = 2 G H, by D M, that is, the double longitude of B C by its latitude. The resulting product will be south or *minus*. The double area of the triangle A C M will be the product of M C by A M, or the double longitude of the course A C by its latitude. The resulting product will be north or *plus*. Adding together, then, the plus products, and subtracting from the minus product, gives as the result the double area of the field.

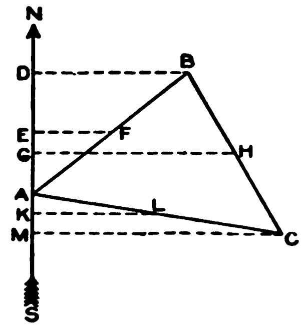


Fig. 64.

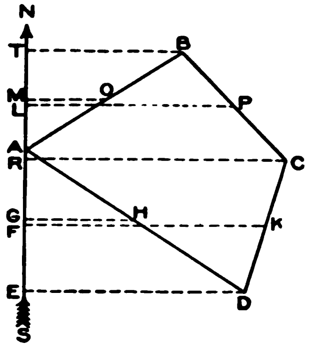


Fig. 65.

We shall next take a four-sided field, as in Fig. 65.

It is evident that the area of the field A B C D is the difference between the sum of the areas of the two trapezoids T B C R and R C D E and the sum of the areas of the triangles A B T and A D E.

The double area of the triangle A B T is the product of B T by A T, or the double longitude of the course A B by its latitude. The result will be a north product or *plus*. The double area of the trapezoid T B C R will be the product of (T B + C R) = 2 L P by T R—that is, the double longitude of the course B C by its latitude. The result will be a south product or *minus*. The double area of the trapezoid R C D E will be the product of (R C + D E) = 2 F K, by R E, or, the double longitude of the course C D by its latitude. The result will be a south product or *minus*. The

Stations	Bearings	Distances	Latitudes N.	Latitudes S.	Departures E.	Departures W.	Double Longitudes	Double Areas +	Double Areas −
1	S. 21° W.	12.41		11.616		4.438	−7.204	83.682	
2	N. 83¼° E.	5.86	0.679		5.821		−5.821		3.952
3	N. 12° E.	8.25	8.053		1.719		+1.719	13.843	
4	N. 47° W.	4.24	2.884			3.102	+0.336	0.969	
							98.494		3.952
							3.952		
						2	94.512		
							47.271		

Area = 47.271 Sq. Chs. = 4 Acres, 2 Roods, 37 Sq. Perches.

double area of the triangle A D E will be the product of E D by A E, or the double longitude of the course A D by its latitude. The result will be a north product or *plus*. Finally, adding together the north products, adding together the south products, and taking the difference of their sums, gives as the result the double area of the field A B C D.

The same principle will apply to any enclosed area, however great the number of the sides. *The area will always be one-half the difference of the sums of the north and the south products arising from multiplying the double longitude of each course by its latitude.*

For systematic computation arrange the work as follows:

Arrange the columns as in the problem on page 83.

Balance the latitudes and departures, putting the corrected quantities above the others in red ink: or else arrange four additional columns, and enter them in their proper places.

Compute the double longitude of each course with reference to a meridian passing through the extreme east or west station. and place the results in another column.

Multiply the double longitude of each course by the corrected latitude of that course, and place north products in one column and south products in another.

Add together the north products and also the south products, and take the difference of their sums. Divide the difference by two, and the result will be the area desired.

If the survey has been made with a Gunter's chain, the result will be in square chains. Divide by ten to reduce to acres.

To test the correctness of the calculation, assume the meridian as passing through the extreme station upon the other side of the field, and carry out the work in detail as before.

We shall now proceed to calculate the content of the field given by the notes on page 81. The corrections to the latitudes will be found on page 82, and the corrected departures on page 83.

The arrangement of the columns for convenient calculation is as described on page 86. Upon making a rough sketch of the courses, it is found that station 3 is the farthest east; and therefore the double longitudes will be calculated beginning with course 3. From the definition previously given, the double longitude of course 3 is equal to its departure = + 1.719. The double longitude of course 4 equals the double longitude of course 3, plus the departure of course 3, plus the departure of course 4 = 1.719 + 1.719 + (– 3.102) = + 0.336. The double longitude of course 1 equals the double longitude of course 4, plus the departure of course 4, plus the departure of course 1 = 0.336 + (– 3.102) + (– 4.438) = – 7.204. The double longitude of course 2 equals the double longitude of course 1, plus the departure of course 1, plus the departure of course 2 = + (– 7.204) + (– 4.438) + 5.821 = – 5.821. Multiplying these double longitudes by their respective latitudes, gives the quantities in the last two columns, the first, third, and fourth being positive, and the second negative. Taking the difference of the sums of the quantities in these columns, and dividing the result by 2, gives the content of the field, 47.271 square chains. Dividing by 10 gives 4.7271 acres. Reduce to roods and perches by multiplying the decimal part by 4 and 40 successively.

The result may now be checked by beginning with the most westerly station, and it will be necessary to recalculate the quantities in the last three columns.

The following problems are taken from "Gillespie's Surveying" (Staley):

EXAMPLES FOR PRACTICE.

Calculate the content of the fields from the data tabulated below. The result, where found in square metres, should be reduced to acres: 1 sq. metre = .000247 acre.

(1)

STATIONS.	BEARINGS.	DISTANCES.
1	N. 34¼° E.	2.73
2	N. 85° E.	1.28
3	S. 56¾° E.	2.20
4	S. 34¼° W.	3.53
5	N. 56½° W.	3.20

Ans. 1 acre, 0 roods, 14 perches.

(2)

STATIONS.	BEARINGS.	DISTANCES.
1	N. 35° E.	2.70
2	N. 83½° E.	1 29
3	S. 57° E.	2.22
4	S. 34¼° W.	3.55
5	N. 56½° W.	3.23

Ans. 1 acre, 0 roods, 15 perches.

(3)

STATIONS.	BEARINGS.	DISTANCES.
1	S. 5° 35′ W.	2,388.88 meters
2	S. 39° 35′ W.	1,060.27 meters
3	S. 50° 25′ E.	3,078.31 meters
4	S. 79° 5′ E.	325.00 meters
5	S. 53° 50′ E.	275.00 meters
6	S. 48° 15′ W.	200.00 meters
7	N. 82° 45′ E.	450.00 meters
8	S. 87° 40′ E.	186.72 meters
9	N.	8,768.12 meters
10	N. 84° 25′ W.	1,898.54 meters
11	S. 5° 35′ W.	3,530.60 meters
12	N. 84° 25′ W.	257.50 meters

Ans. { 4,999 acres
3 roods.
$39\frac{96}{100}$ sq. rods.

Supplying Omissions. The method of latitudes and departures may be applied to supplying any two omissions in the field notes, as will be explained in connection with the "Use of the Transit."

Azimuth. The azimuth of a line is the horizontal angle which the line makes with some other line taken as a meridian. It differs from bearing in that it is measured continuously from 0° to 360°. All descriptions of property must be given in terms of bearings, but line surveys with either the compass or the transit had better be given in terms of the azimuth.

In astronomical and geodetic work it is customary to reckon azimuth from the *south point around through the west*, through 360°. For the ordinary operations of surveying, however, it is better to measure the azimuth from the north point to the right through 360°.

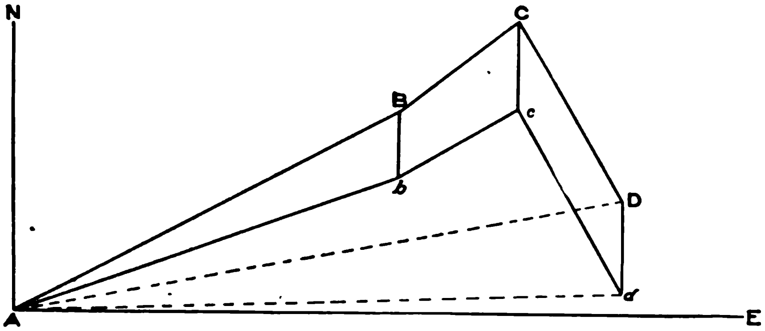


Fig. 66.

RESURVEYS.

Where the boundary lines of a farm or town have been obliterated and the corners lost, it is often necessary to make resurveys in order to re-establish them. If the corners can be found by reliable evidence, they must be accepted as corners even though the second bearings and lengths of the lines indicate different points.

It sometimes happens that some corners can be found while others cannot. In such cases a series of random lines is to be run with the old bearings, or with the old bearings corrected for a change in declination of the needle between the two dates.

As an example, let the records in an old deed give the length and bearings of three lines as follows: (See Fig. 66.)

A*b* N 60° E 10 chains.
***bc* N 45° E 4 chains.**
***cd* S 45° E 8 chains.**

There being no definite data at hand to determine the change in the magnetic declination between the dates of the two surveys, the lines AB, BC and CD are run with the given bearings and distances from the known corner A. The old corners *b* and *c* cannot be found; but on arriving at D the old corner *d* is discovered at a point 20.4 links S and 12° W from D It is required to locate the old corners *b* and *c*.

By the method of latitudes and departures explained before, the lengths of the lines DA and *d*A may be computed. They are: for DA, south 82° 47′, west 17.29 chains; for *d*A, south 83° 26′, west 17.22 chains.

Now the error D*d* between the two corners is due to two causes: (1) the continued variation in the magnetic bearings of the old surveys, (2) the difference in the length of the chains used. The first cause alters the polygon A*bcd*A around the point A by a small angle. The second cause alters the length of the sides in a constant ratio. The difference between the bearings DA and *d*A is the constant angle, while the ratio of the length of the old lines is the constant ratio. To find the bearings of the old line, therefore, each of the given bearings is to be corrected by the amount 83° 26′ minus 82° 47′ = 0° 39′. To find the length of the old line each of the given lengths is to be multiplied by $\frac{17.22}{17.29} = 0.996$.

Suppose now that the work of computation has been done with such precision that the error in chaining must be regarded as lying in the old survey. Applying these results, we find the adjusted bearings and lengths of the old line to be,

A*b* = N 60° 39′ E 9.96 chains.
bc = N 45° 39′ E 3.99 chains.
cd = S 44° 21′ E 7.97 chains.

With the new data the line may be rerun and the corners *b* and *c* located, a check on the field work being that the lost line should end exactly at *d*.

It is, however, not difficult to compute the length and bearings of B *b* and C *c*, so that *b* and *c* may be located from the points B and C.

Since the angle $B\,A\,b$ is small, the triangle $B\,A\,b$ may be considered similar to the triangle $D\,A\,d$. We will then have the proportion:

$$B\,b : D\,d :: A\,B : A\,D.$$

Or,

$$B\,b = D\,d \times \frac{A\,B}{A\,D} = \frac{.204 \times 10}{17.29} = 11.8 \text{ links.}$$

A similar proportion may be written for the side $B\,c$, and the result added to the value of $B\,b$.

The same principle may be used to determine the bearings of $B\,b$ and $C\,c$, so that, with the lengths and bearings of these lines determined, the most probable location of the old corners b and c can be fixed.

EXAMPLE FOR PRACTICE.

The records of an old survey read as follows:

"Commencing at a point marked No. 5 and running N 62° E 14 chains to a stake marked A, thence running N 43½° E 8.00 chains to a stake marked B, thence N. 5° W. 12.00 chains to a stake C, thence N 72½° E. 10.25 chains to a stake D, thence S 12° W 6.43 chains to a stake marked No. 3. On running the lines, the end of the last one, instead of being at a stone marked No. 3, was 0.62 chain due E from it." Find the adjusted bearings and lengths of the old lines; also find the distance and direction from each station of the new survey to the corresponding corner of the old.

DIVISION OF LAND.

The method of latitudes and departures is especially useful in the division of land. The problem is usually as follows: Given the lengths and bearings of the sides of a field containing a certain area; it is required to divide the area into certain parts by a line running in a certain direction, in which case it is necessary to determine the starting point of the dividing line. Or it is required that the line shall begin at a certain point, in which case it is necessary to determine the direction of the line.

A certain field is described as follows:

1	N. 63° 51′ W.	6.91 Chs.
2	N. 63° 14′ W.	7.26 "
3	N. 69° 35′ W.	3.34 "

4	N. 77° 50′ W.	6.54 Chs.
5	N. 31° 24′ E.	14.38 "
6	N. 31° 18′ E.	16.81 "
7	S. 68° 55′ E.	13.64 "
8	S. 68° 42′ E.	11.54 "
9	S. 33° 45′ W.	31.55 "

Beginning at a point upon the side 91, it is required to divide the area into two equal parts of 37 acres by a line having a bearing of N. 68° 46′ W. Some preliminary calculations will be necessary to determine the starting point of the dividing line such that the resulting area will be nearly that desired, and this dividing line will be practically parallel to a line connecting stations 7 and 9. Call the dividing line *A B* (see Fig. 67), and if this line begins at a point 15 chains from station 9, the length of *A B* will be 24.528 chains; that of *B* 7 will be 14.90 chains. We shall now proceed to calculate the area by latitudes and departures, beginning with station 9. The calculations are shown in the following table, and the result, 36.5186 acres, is short of the required area by 0.4814 acre or 4.814 square chains.

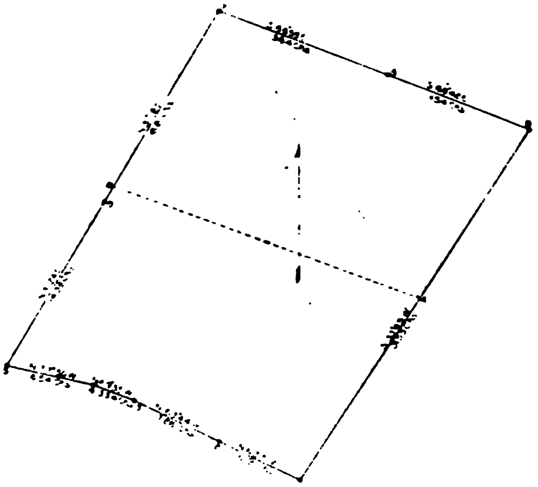


Fig. 67.

Station	Bearings	Distances	Latitudes N.	Latitudes S.	Departures E.	Departures W.	Double Longitudes	Double Areas +	Double Areas −
9	S. 33° 45′ W.	15 00		12.472		8 334	− 8.334	103.942	
A	N. 68° 46′ W.	24 528	8 883			22 863	−39.531		351.154
B	N. 31° 18′ E.	14 90	12.731		7.741		−54 653		695.787
7	S. 68° 55′ E.	13.64		4.907	12.727		−34.185	167.746	
8	S. 68° 42′ E.	11.54		4 192	10.752		−10.706	44.880	
								316.568	1046.941
									316.568
								2	730.373
									365.186

Area = 36.5186 Acres.

Our line *A B* must therefore be moved farther south such a distance that the area enclosed between the first and second positions shall equal 4.814 square chains. Considering this area as a rectangle (which it will be nearly), the line *A B* will be moved south $\frac{4.814}{24.528} = 0.1961$ chain, or, say, 0.2 chain. The line 9 *A* will be therefore 15.2 chains in length. The length of *A B* will not be materially changed. *B* 7 will now be 15.1 chains in length, while 78 and 89 will be the same as before. The latitudes and departures of 9 *A*, *A B*, and *B* 7 must be recalculated, as well as the double longitudes of all of the courses. The calculations are found in the following table, and there results an area equal to 37.015 acres.

STATION	BEARINGS	DISTANCES	LATITUDES N.	LATITUDES S.	DEPARTURES E.	DEPARTURES W.	DOUBLE LONGITUDES	DOUBLE AREAS +	DOUBLE AREAS —
9	S. 33° 45′ W.	15.20		12.638		8.445	— 8.445	106.728	
A	N. 68° 46′ W.	24.528	8.883			22.863	—39.753		353.126
B	N. 31° 18′ E.	15.10	12.902		7.845		– 54.771		706.655
7	S. 68° 55′ E.	13.64		4.907	12.727		–34.199	167.814	
8	S. 68° 42′ E.	11.54		4.192	10.752		–10.720	44.938	
								319.480	1059.781
									319.480
								2	740.301
									370.150

AREA = 37.015 ACRES.

Referring to Fig. 67, starting at a point *A* on 91, 12.25 chains from station 9, it is required to find the length and bearing of *A B* such that the area 9 *A B* 7 8 9 shall equal 32 acres.

First draw a line from *A* to station 7, and by latitudes and departures calculate the area *A* 7 8 9 *A*, and determine the length and bearing of *A* 7. Call this latter area *H*. Then the area *A B* 7 *A* must equal 32-*H*. From the point *B*, erect a perpendicular *B C* to the line *A* 7. The area of *A B* 7 *A* will equal $\frac{A\,7}{2} \times B\,C = (32-$

H); $\therefore$ $B\,C = \dfrac{2\,(32-H)}{A7}$. Therefore $B\,7 = \dfrac{B\,C}{\sin\,B\,7\,C}$. In the triangle $A\,B\,7\,A$ we now have two sides and the included angle from which to calculate the length and bearing of $A\,B$.

THE TRUE MERIDIAN.

In order to ascertain the true meridian of a given place, several methods may be pursued. The general practice is to use the star Polaris at culmination or elongation. This star is on the meridian, nearly, when a plumb line covers it and the star Zeta, the next to the end of the handle of "The Dipper." See **Fig. 68.**

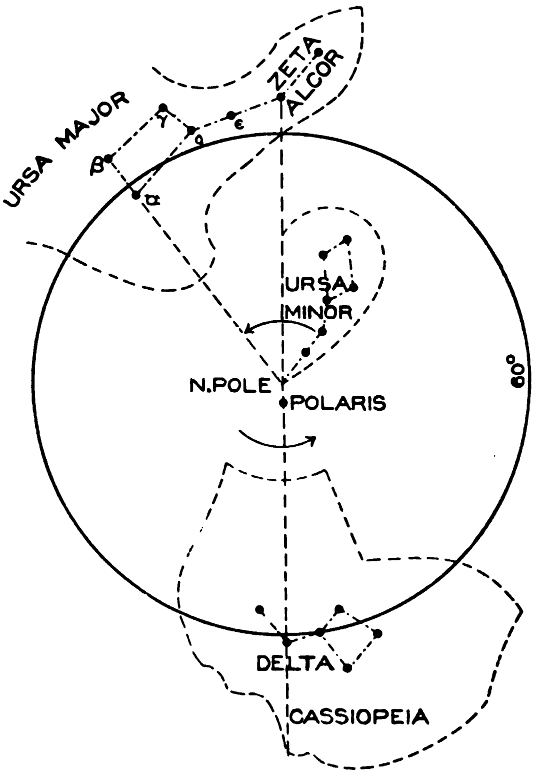


Fig. 68.

When Polaris is on the meridian, as illustrated in this instance, it is said to be at "culmination." This star is often referred to as the north or pole star. It is about $1\frac{1}{4}^\circ$ from the pole, and revolves around the pole once every 23 hours and 56 minutes. Thus it is apparent that it comes on the true meridian twice each day. The arrows in the figure indicate the direction of the rotation.

To Determine the True Meridian by the Compass. *With Polaris at Eastern or Western Elongation.* To determine the true meridian by means of the compass, take a plumb-line, and attach one end of the line to any suitable support situated as far above the ground as practicable, so as to have a clear field of view about 20 feet away. A board nailed on a telegraph pole, tree, or post at right angles, will suffice for this purpose. The plumb-bob may be of any suitable material, of about 5 lbs. in weight, as a brick, stone, iron ring, or coupling. It will serve the same purpose, with as accurate results, as the most highly polished or carefully manufactured plumb-bob. The plumb-line should be about 25 feet in length, depending upon the latitude of the place, since the altitude of the pole above the horizon at any place is equal to the latitude of that place.

Illuminate the plumb-line just below its support by means of a bull's-eye lantern, lamp, or candle, care being taken not to obliterate the line from the view of the observer. The best way is to screen the light, and throw the light on the plumb-line by means of a reflector.

Next unfasten one of the uprights of the compass, and place it on a horizontal rest at some convenient point south of the plumb-line, say 30 feet in an east or west direction, and in such a position that when viewed through the peep-sight, Polaris will appear about two feet below the support of the plumb-line. It is customary to determine this position by trial the night before the observation.

About 25 minutes before the time of elongation, as per table on page 130, bring the peep-sight into the same line of sight with the plumb-line and the star Polaris. Before reaching elongation, the star will move away from the plumb-line, to the east for eastern elongation, and to the west for western elongation. Hence, by moving the peep-sight in the proper direction - that is, east or west—the star can be kept on the plumb-line until it appears to remain stationary, thus indicating that it has reached its point of elongation. The peep-sight will now be secured in place by a clamp or weight, with its exact position marked on the rest. Now defer all further operations until the next day.

The next morning place a slender flag or ranging pole at a distance of 200 or 300 feet from the peep-sight, and exactly in line with the plumb-line. Next carefully measure this distance, and take from the table (page 130) the azimuth of Polaris, corresponding to the latitude of the station of observation; find the natural tangent of this azimuth, and multiply it by the measured distance from the peep-sight to the rod. The product will express the distance to be laid off from the rod, exactly at right angles to the direction already determined—that is, to the west for eastern elongation, and to the east for western elongation; and this point with the peep-sight, will define the direction of the meridian with sufficient accuracy for the needs of local surveyors.

The position of the pole star may be found by means of the two stars β and α in the bowl of the "The Dipper" (Fig. 68), which are called the "pointers" because of their pointing approximately to the pole star.

THE TRANSIT.

Construction. The transit is used for measuring horizontal and vertical angles directly, and for measuring bearings indirectly. It consists of a telescope mounted in standards attached to a divided horizontal plate, the telescope serving to define accurately the line of sight; while the horizontal plate, divided into degrees, minutes, and twenty or thirty seconds of arc, makes it possible to measure small horizontal angles. The instrument is provided with a three- or four-screw leveling base, by means of which it is attached to the tripod.

The telescope is similar in construction to that of the Wye level, but is shorter and of less magnifying power, a power of from 24 to 26 diameters being about the average for the ordinary transit. The eye-piece may be either inverting or erecting, but the former is to be preferred.

Since the principal function of the transit is to secure alignment, the telescope must be capable of movement in a vertical plane, and to that end is supported in the standards by a transverse axis, permitting the telescope to be "transited," that is. turned through a complete vertical circle.

For measuring horizontal angles the instrument is arranged with an upper and a lower motion, sometimes called the upper and the lower "limb." The lower limb is supported by the leveling base by means of a hollow conical axis; and into it is fitted, in turn, the conical axis of the upper limb. Each limb may be turned independently of the other, or they may be clamped together and to the leveling base. The lower limb carries the divided circle and the upper limb the vernier. For ordinary purposes the circle is divided to one-half degrees, and reads to single minutes by means of the vernier. It may also be divided so as to read to 20 or 30 seconds, and occasionally to 10 seconds. The divisions of the circle, however, should not be so crowded as to render the reading difficult, and the graduations should be properly adjusted to the magnifying power of the telescope.

The verniers may be set at right angles to, or parallel with the line of sight, or at 30° thereto. With the verniers parallel with the line of sight—that is to say, directly under the telescope—or making an angle of 30° with the line of sight, the observer can read the angles without moving from his position, thereby avoiding the risk of disturbing the instrument by walking around it. See Fig. 69.

For leveling the instrument, there are provided two level tubes set at right angles to each other. These are shown in the figure. One of them is attached to the upper plate, while the other may be attached either to the upper plate or to one of the standards. On account of lack of space these level tubes are quite short.

The four-screw leveling base may consist of two parallel plates connected to each other by a one-half ball and socket joint, or the upper plate may be replaced by a ribbed casting. The four leveling screws rest in cups upon the lower plate and extend through the upper plate or casting. The leveling base is attached to the instrument proper, and the whole is attached to the tripod by screwing to a casting firmly attached to the legs. The vertical axis is furnished with a hook, to which may be attached a plumb-line for the accurate centering of the instrument. A shifting center is also provided, by means of which, after the instrument has been approximately centered over a stake, it may be accurately adjusted by loosening the leveling screws and shifting the instrument upon the lower leveling base. See Fig. 69.

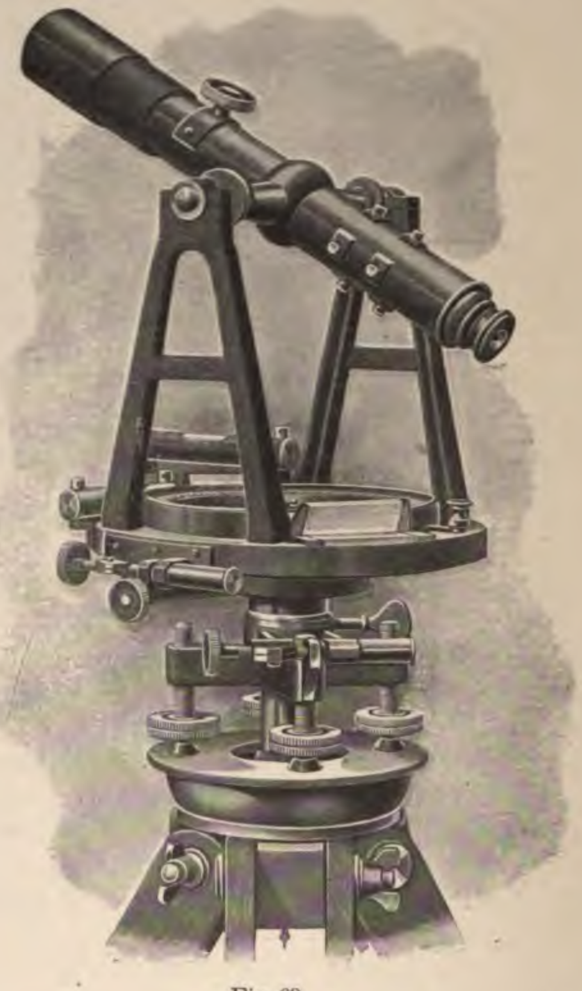


Fig. 69.

The three-screw leveling base is necessarily larger and differs in detail from the four-screw. The upper plate carrying the screws is permanently attached to the instrument; and the lower ends of

U. S. GEOLOGICAL SURVEY CAMP ON CHOPAKA MOUNTAIN, WASHINGTON the screws rest upon the tripod casting, to which it is attached by a single center screw fitted with a strong spiral spring that engages upon a thread cut upon the vertical axis of the instrument. See Fig. 72.

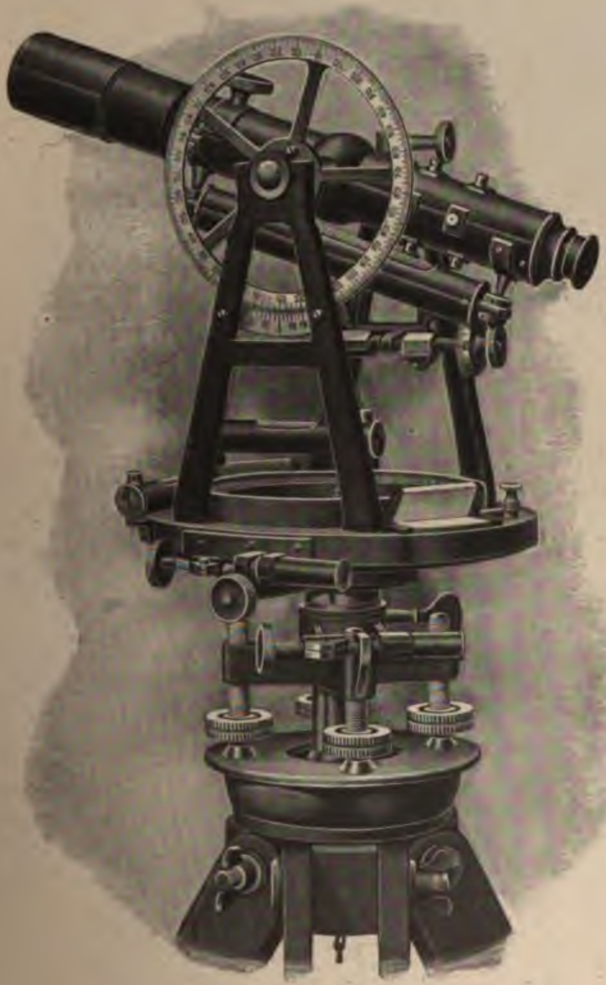


Fig. 70.

The four-screw base commends itself from the fact that it can quickly be leveled approximately; and, no matter how much the threads are worn, the instrument can be brought to a solid bearing.

33127A

The three-screw base, however, is more easily manipulated, and all danger of binding the screws and springing the plates is obviated. Whichever type of instrument is preferred, the screws should work smoothly and evenly, and the pitch should be adjusted to the sensitiveness of the bubbles.

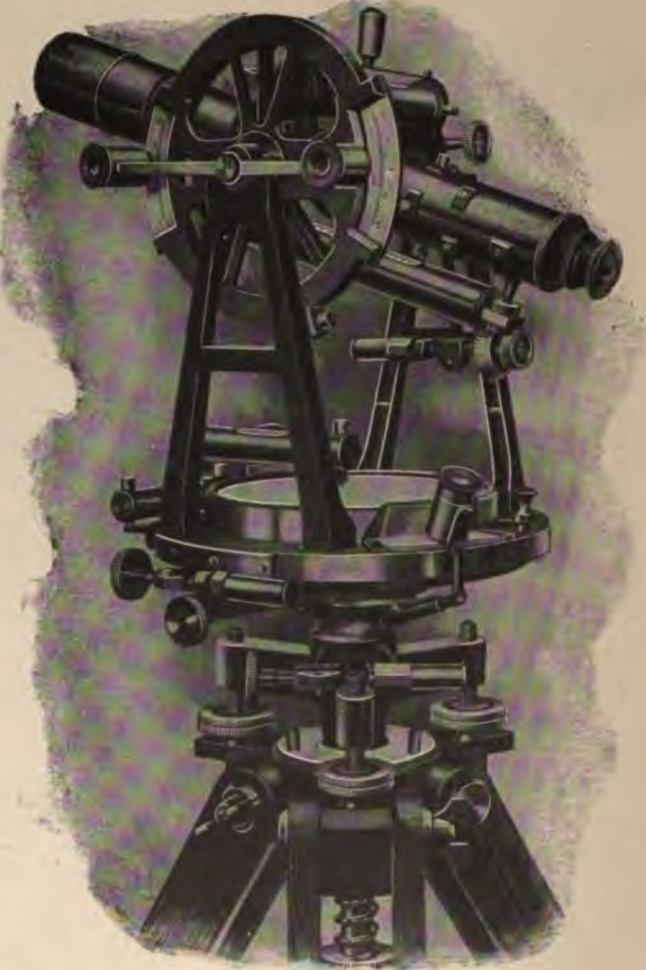


Fig. 71.

Most transits are fitted with a compass set in the upper plate

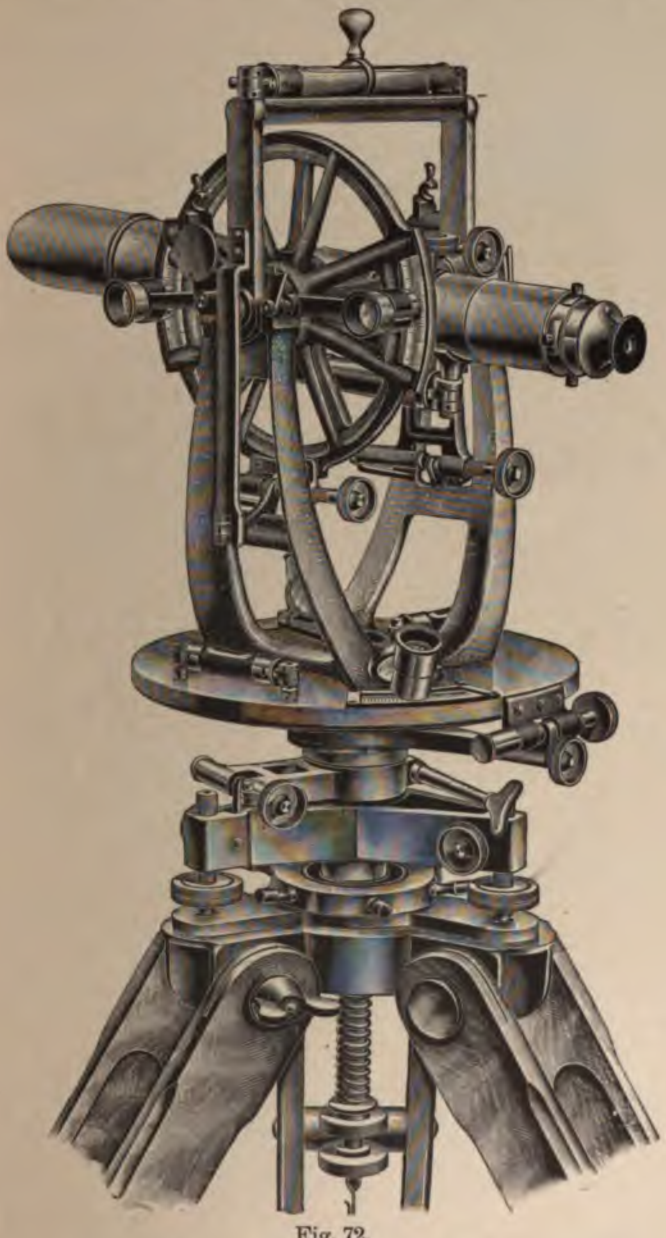


Fig. 72.

between the standards; but for city work, triangulation, etc., the compass is dispensed with.

For measuring vertical angles, the transit is fitted with a vertical arc or circle divided usually to one-half degrees, and

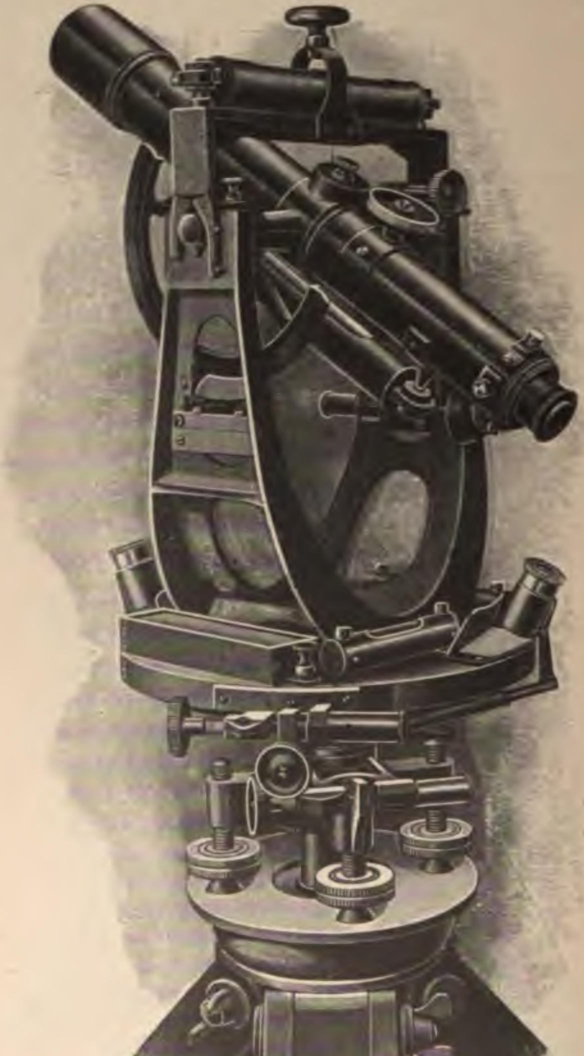


Fig. 73.

reading to single minutes by the vernier. A level tube may also be attached to the under side of the telescope; and when this is provided the transit may be used as a leveling instrument. A striding level resting upon the standards may also be provided, by means of which the instrument can be more accurately leveled than by the short levels upon the upper limb. See Fig. 70.

The telescope should always be provided with stadia wires, either fixed or adjustable, though the former are preferable. See article on "Stadia."

The gradienter screw is a device attached to the clamp of the telescope, by means of which grades can be established, and horizontal distances, vertical angles, and differences of level can be measured with great rapidity. See article on "Gradienter" in Part III.

Surveyor's Transit. This instrument is the plain transit, capable usually of measuring horizontal angles only, but occasionally fitted with a vertical circle or arc for measuring vertical angles. See Fig. 69.

Engineer's Transit. When the instrument is provided with a vertical circle or arc, a level underneath the telescope, with or without gradienter screw, it is called the engineer's transit. See Fig. 70.

Tachymeter. This term, meaning *rapid measurer*, has of recent years been applied to an instrument having a level attached to the telescope, a vertical arc or circle, and stadia wires. Such an instrument is adapted to the rapid location of points in a survey, since it is capable of measuring the three co-ordinates of a point in space, *i. e.*, the angular co-ordinates of altitude and azimuth, and the radius-vector or distance. The compass and gradienter are auxiliaries in the measurement of angles; and an instrument having them in addition to the essential features mentioned above, is more perfectly adapted for tachymetric work. See Fig. 71.

Theodolite. This term is applied to an instrument so constructed that the telescope will not transit, but, in order to take backward sights, the telescope must be lifted out of its supports and turned end for end. See Fig. 73.

Transit-Theodolite. This name is applied to an instrument in which the telescope not only can be transited, but also lifted out of its supports and turned end for end. See Fig. 72.

Adjustment. When used merely as an angle-measurer, the following adjustments should be tested and, if necessary, corrected:

1st. *To ascertain if the bubble tubes are perpendicular to the vertical axis of the instrument.*

To test, attach the instrument to the tripod and "set up" firmly on solid ground, preferably shaded from sun and wind. Revolve the transit upon its vertical axis so as to bring the bubble tubes parallel to a pair of diagonally opposite leveling screws. Bring the bubble of one of the tubes to the center by means of these screws. Do the same with the second bubble tube. Adjusting the second tube will throw the first one out, but repeat the alternate operations until each bubble stands in the center of its tube. Now revolve the instrument upon its vertical axis through 180°, and note if the bubble of each tube still stands in the center. If so, the tubes are in adjustment.

If the bubble of either tube runs to one end, bring it half-way back to the center by raising the opposite end of the tube by means of the capstan-headed screw. Relevel the instrument by the leveling screws, and again test the tubes. Repeat the operation, until the bubbles stand in the centers of the tubes in all positions of the instrument. It is advisable to carry out this adjustment as precisely as possible, as it will facilitate the remaining adjustments. If after several trials, it is found impossible to adjust the bubbles to the centers of the tubes, either the vertical axis is bent or the plates are sprung, and the instrument should be sent to the maker for correction. If one tube adjusts and the other does not, the fault is in the tube, and a new one should be ordered.

2d. *To make the line of collimation revolve in a plane, or, in other words, to make the line of collimation perpendicular to the horizontal axis of the telescope.*

To test, having made the first adjustment, level the instrument carefully and clamp the upper limb. Drive a stake into the ground about 300 feet *ahead* of the instrument, and drive a tack in the head of the stake. By means of the lower motion revolve the instrument on its vertical axis until the intersection of the cross-hairs approximately covers the tack. Now clamp the lower motion, and carefully adjust the line of sight upon the tack by means of the lower tangent screw. Without disturbing either the upper or the lower limb, transit the telescope, that is, revolve it vertically, and sight to a tack in the head of a stake driven into the ground about 300 feet *behind* the instrument. Carefully adjust the tack to the intersection of the cross-hairs. Now unclamp the lower motion, and revolve the instrument upon its vertical axis until the intersection of the cross-hairs again covers the tack in the first stake. Clamp the lower motion, adjust the line of sight carefully by means of the tangent screw, again transit the telescope, and sight in the direction of the second stake. If the intersection of the cross-hairs falls upon the tack in the second stake, the line of collimation is in adjustment. If it does not, it will have to be adjusted.

In Fig. 74, A is the position of the instrument, and B is the forward stake. If the instrument is in adjustment, the line of sight after transiting the telescope and revolving upon the vertical axis should strike the point B′. If the instrument is not in adjustment, the line of sight after transiting the telescope will in the first instance strike some point as C. Drive a stake at this point and carefully center a tack. After revolving the instrument upon its vertical axis and again transiting the telescope, the line of sight will fall at a point C′ as far on one side of B′ as C was on the other. Drive a stake at C′ and carefully center it. Carefully measure the distance C C′; and center a stake at B′, half-way between the two points. Now, by means of the capstan-headed screws attached to the diaphragm carrying the cross-hairs, move the cross-hairs until their intersection covers the point B″, midway between B′ and C′. Now repeat the operation of testing the adjustment and correcting the position of the line of collimation, until the points B and B′ are in the same straight line.

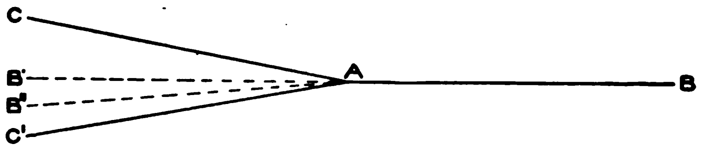


Fig. 74.

It is necessary only that the line of collimation shall be accurately in adjustment; but for convenience in using the transit as an angle-measurer it is desirable that the vertical cross-hair be at right angles to the horizontal axis of the telescope when the instrument is level.

To test this, set up the instrument at some convenient point, 200 or 300 feet from a wall, tree, or other convenient object, upon which a point is clearly defined by a tack or otherwise. Carefully level the instrument, and cover this point accurately with the lower extremity of the vertical hair. Clamp the horizontal axis of the telescope; and by means of the tangent-screw slowly move the telescope in a vertical plane, and note if the hair continues to cover the point from one extremity to the other. If it does, the hair is in its proper position. If not, loosen the diaphragm screws and turn the diaphragm vertically until the hair covers the point from end to end. This adjustment will disturb the last one and the two must be tested and corrected alternately until in perfect adjustment.

If the transit is to be used for leveling, it is necessary that the *horizontal* cross-hair be in the optical center of the object glass.

To test, set the instrument up firmly 200 or 300 feet from a wall, tree, or other convenient object, and, after leveling, carefully center the intersection of the cross-hairs upon a well-defined point. Clamp the axis of the telescope, turn the instrument upon its vertical axis through 180°, and carefully center a point upon the intersection of the cross-hairs in this new position. Clamp the vertical axis, unclamp the telescope axis, transit the telescope, and carefully center the intersection of the cross-hairs upon the first point. Now clamp the telescope, loosen the vertical axis, and again revolve the instrument through 180°. If the line of collimation again strikes the second point, the horizontal cross-hair is in adjustment. If not, carefully center this third point, bisect the distance between the second and third points, and move the cross-hair diaphragm until the intersection of the cross-hairs covers this fourth point. This adjustment will disturb the last two, and the three must be repeated in succession until accurately adjusted.

3d. *To make the horizontal axis of the telescope perpendicular to the vertical axis of the instrument.*

To test, set up the instrument as explained for the last adjustment, and, after leveling, center carefully a point at each extremity of the horizontal cross-hair. Turn the instrument upon its vertical axis and transit the telescope, bringing one extremity of the horizontal cross-hair upon one of the points previously established. If the other extremity coincides with the second point, the axis of the telescope is in adjustment.

If the axis is out of adjustment, the method of procedure is best illustrated by Fig. 75.

A A′ is the line covered between the extremities of the horizontal wire or hair when the axis of the telescope is in adjustment. If it is not in adjustment, the wire will in the first position of the telescope cover the line A B, and in the second position the line A B′. Therefore bisect the distance B B′, and raise or lower the adjustable end of the telescope axis until the wire covers A A′. Now repeat the test, and the correction if necessary.

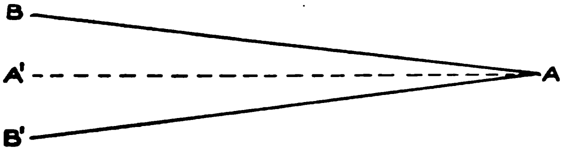


Fig. 75.

4th. *To make the axis of the telescope bubble tube parallel to the line of collimation of the telescope.*

This adjustment should be tested and corrected by the "peg" method as follows: Select a piece of comparatively level ground, drive a stake, "set up" the transit over it, and carefully level by the *plate* levels. Next drive two stakes into the ground, one in front of the transit and the other at the same distance behind it. In Fig. 76, C is the position of the transit, and A and B are two stakes, each 150 feet from C. D is a fourth stake behind B and in line with it from C. The transit being leveled by the plate levels, bring the bubble of the telescope tube to the center of the tube, by means of the tangent-screw attached to the horizontal axis of the telescope. Hold a level rod upon A, adjust the target to the

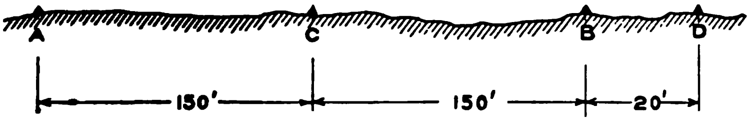


Fig. 76.

horizontal cross-hair, and note the reading. Unclamp the lower motion, turn the transit upon its vertical axis, and note the reading of a rod held upon B. The difference of the readings of the rod held upon the two points will give the true difference of level, no matter how much the telescope level may be out of adjustment.

Now take up the transit and remove it to the point D. Carefully level the transit by the plate levels, and again bring the bubble of the telescope tube to its center. Hold the rod upon the point B and note its reading. Do the same at the point A, and take the difference of the two readings. If the telescope level is in adjustment, this difference will be the same as found when the instrument was over the point C. Otherwise the tube is out of adjustment and will be corrected as follows:

Let x represent the difference of level of A and B when the transit is at C.

Let y represent the difference of level of A and B when the transit is at D.

Let z represent the difference between x and y.

If y is greater than x, subtract z from the rod reading upon A for the transit at D, and set the target at this new reading. Revolve the telescope upon its horizontal axis, by means of the tangent-screw, until the horizontal wire accurately bisects the target. Now clamp the telescope axis, and bring the bubble to the center of the tube by means of the capstan-headed screw at one end of the tube. Again hold the rod upon B, and then upon A, and take the difference of their readings. If this difference now agrees with the true difference of elevation of the two points, the adjustment is complete. Repeat the operation as often as may be necessary.

If y is less than x, add z to the rod reading upon A for the transit at D, and set the target at this new reading. Bisect the target by the horizontal cross-hair as before, clamp the horizontal axis, and bring the bubble to the center of the tube. Test and repeat as described before.

Some transits are provided with an adjustable vernier to the vertical circle or arc, which should read 0° when the telescope is horizontal. The former adjustment having been completed, the vernier can then be readily fixed in place.

The cross-hair intersection should be in the center of the field of vision of the eye-piece, and this adjustment may be made by means of the capstan-head screws attached to the eye-piece tube.

To "set up" the transit. Lift the instrument out of the box by placing the hands underneath the plates. Avoid lifting it by the telescope or the standards. In attaching it to the tripod be careful that the threads engage properly, and screw it down firmly. Examine the tripod legs, and see that they are properly attached to the tripod head, neither too tight nor too loose. See that the tripod shoes are tight, and, before taking up the instrument, lightly clamp all the movable parts to prevent unnecessary wear and straining. Carry the instrument in the most convenient way, taking care not to hit it against trees, lamp-posts, doors, etc.

To center the transit over a stake, rest one leg of the tripod upon the ground, and, grasping the other legs, pull the instrument in the proper direction to cover the stake. Now attach the plumb-line, and after bringing it to rest as close to the top of the stake as possible, note if the point is directly over the point in the stake. If it is not too far off the center, it may be brought closer by forcing the opposite leg into the ground or by a further spreading of the legs. After the instrument has been approximately centered, it may be accurately adjusted by means of the shifting head. The operation of "setting up" is difficult of description, and facility can be attained only by practice. Avoid having the plates too much out of level, as this will result in unnecessary straining of the leveling screws and plates.

Having centered the instrument over the stake, level it up by the levels upon the horizontal plate. To do this, turn the instrument upon its vertical axis until the bubble tubes are parallel to a pair of diagonally opposite plate-screws. Now, as you stand facing the instrument, grasp the screws between the thumb and forefinger, and turn the thumb of the left hand in the direction the bubble must move. Turn both thumbs in, or both thumbs out. Adjusting one tube will disturb the other, but adjust each alternately until the bubble of each remains in the center.

To measure a horizontal angle by means of the transit. Set up the transit over the point C, Fig. 77. Set the verniers to read 0°, and clamp the upper limb. Now revolve the transit upon its vertical axis by the lower motion, and sight to A. Clamp the lower motion, and accurately adjust the intersection of the cross-hairs to the point by means of the lower tangent-screw. Now unclamp the upper limb, and turn it upon its upper vertical axis to the point B. Clamp the upper limb and adjust the line of sight by the upper tangent-screw. The angle will now be found recorded upon the horizontal circle. If it becomes necessary to repeat the angle, loosen the lower motion, and, without disturbing the upper plate, turn the instrument back to the point A. Next clamp the lower motion, loosen the upper, and turn the telescope to the point B. The sum of the two measured angles will now be found recorded upon the horizontal circle. Repeat as often as necessary, and divide the total horizontal angle by the number of repetitions for the probable value of the angle A B C.

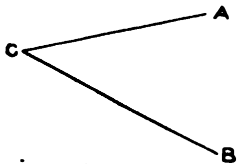


Fig. 77.

The operation of **laying off** a certain angle is essentially the same as the preceding, except that after the point A has been centered and the required angle laid off upon the horizontal circle, the tack in the stake B must be moved back and forth until it is accurately centered at the intersection of the cross-hairs.

To survey a series of lines by means of the transit. "Set up" the transit over the point A, Fig. 78, and make the verniers read 0°. Have the north end of the plate *ahead*, that is, in the direction of the survey. If a true meridian line has previously been laid out, the declination of the needle may be determined from it. Without disturbing the upper plate, turn the transit upon its lower motion, and center upon B. Let the needle down upon its pivot, and as soon as it has come to rest take the bearing of the line AB. To measure the length of the line, hold one end of the tape or chain directly under the point of the plumb-bob, and send the head man in the direction of B. As he reaches the end of his tape, place him accurately in line by the vertical hair. For this purpose

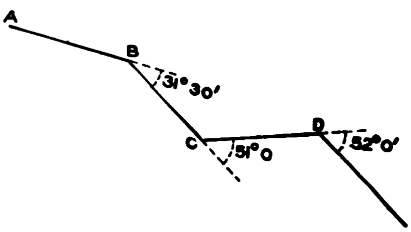


Fig. 78.

the telescope should be turned in a vertical plane to bring the intersection as closely as possible to the top of the stake. Now repeat this operation until the point B is reached. Move the transit to the point B, and set it up as before with the north end of the plate ahead. Transit the telescope, and examine the verniers to see if they read 0°. By means of the lower motion, center upon A, lower the needle, and take the bearing. Now clamp the lower motion, transit the telescope, and revolve the upper plate so the telescope points to C. Read the angle, which is that between A B produced and B C. Also read the bearing from the compass. Now measure B C as explained before, take up the instrument, and set it up at the point C. Continue thus until the series of lines have been surveyed.

The angles measured are those indicated by the dotted lines (Fig. 78), and are called **deflection angles.**

It is desirable in work of this character to calculate the bearing or azimuth of a line from the deflection angle, and to check the result by the compass. Referring to the figure, the records of the survey will be kept as follows, using the left-hand page of the transit or field book and starting from the bottom of the page:

STATION.	DISTANCE.	DEFLECTION.		COMPASS.	DEDUCED BEARINGS.
		LEFT.	RIGHT.		
7 + 95	275		52° 0′	S 52° 45′ E	S 52° 30′ E
5 + 30	265	51° 0′		N 75° 15′ E	N 75° 30′ E
2 + 90	240		31° 30′	S 53° 45′ E	S 53° 30′ E
0	290			S 85 E	

It is not absolutely necessary in the method described above, that the verniers should be set to read 0° before aligning the instrument, provided that the verniers are read before turning off the angle. For instance, if the verniers read 40° 15′ after the instrument is set up over a stake, and after sighting along a certain line, read 60° 15′, the angle between the two lines is the difference of the reading of the verniers, or 20°.

As already explained under "the compass," the direction of a line may be given by its azimuth. If azimuths are computed from the north to the right through 360°, the azimuths for the preceding case will be as follows, as illustrated by the diagram:

Since the bearing of the first line A B (Fig. 79), given by the compass, is S 85° E, its azimuth will evidently be the difference between 180° and 85°, or 95°. Since the second line B C deflects to the right by 31° 30′, its azimuth will evidently be the sum of the angles 95° and 31° 30′, or 126° 30′. Since the third line C D deflects to the left 51° 0′, its azimuth will be the difference of the angles 126° 30′ and 51° 0′, or 75° 30′. The fourth line D E deflects to the right 52° 0′, and therefore its azimuth will be the sum of the angles 75° 30′ and 52° 0′, = 127° 30′.

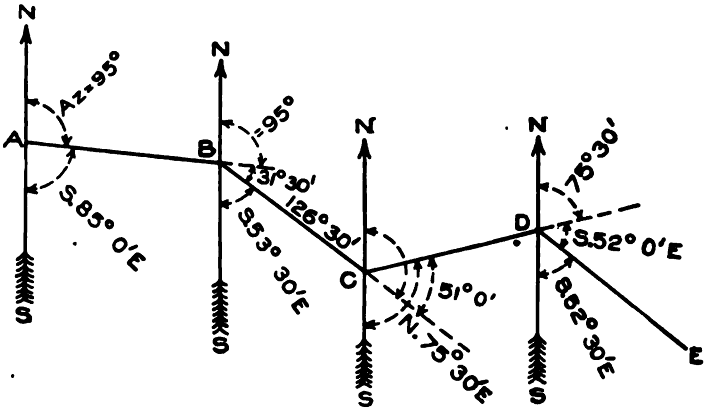


Fig. 79.

The same diagram may serve to illustrate the method of deducing the bearings of a series of lines from the deflection angles. Since the bearing of the first line as given by the compass is S 85° E, and the second line deflects to the right 31° 30′, it is evident that this second line decreases its easting by that amount, so that its bearing will be the difference between 85° and 31° 30′, = S 53° 30′ E. Since the third course deflects to the left by 51° 0′, its bearing to the east will be increased by this amount, but will pass into the northeast quadrant by 14° 30′, making its bearing 90°—14° 30′, = N 75° 30′ E. The fourth course deflects to the right 52° 0′, returning to the southeast quadrant by 37° 30′, making its bearing 90°—37° 30′, or S 52° 30′ E.

Traversing. This is a method of observing and recording the directions of a series of lines of a survey, so as to read off, upon the horizontal circle, the angles that the lines make with some other line of the survey, which may be either a true meridian or some line adopted as a meridian for that survey.

Before starting out upon a traverse, it is best to lay out upon the ground a true meridian, either from observations on Polaris or by means of the "Solar transit," as will be explained later on. This line should be 300 or 400 feet in length, clearly defined by stakes carefully centered, one of the stakes preferably being the first station of the survey. The transit can now be set over this stake, and the line of sight carefully centered upon the second stake by means of the lower motion, the verniers first having been set to read 0°. The subsequent operations can best be illustrated by a diagram.

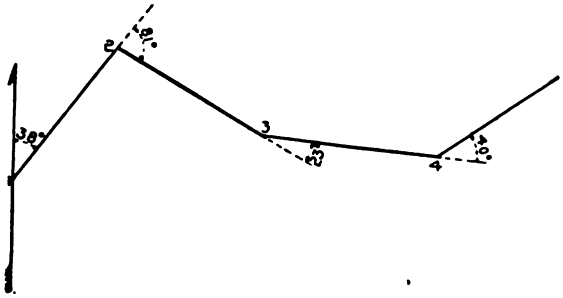


Fig. 80.

First lay out a meridian through station 1 (Fig. 80), and define it by a stake driven 300 or 400 feet away towards N. Both of these stakes should be carefully "witnessed," that they may be recovered at any time. To begin the survey, carefully center the transit over station 1, with verniers set to zero; turn the instrument upon its lower motion until the line of sight approximately covers the stake at the north end of the meridian, and carefully center it by the lower tangent-screw; lower the compass needle (if there is one), and note and record the magnetic declination. Next, with the lower motion securely clamped, unclamp the upper motion, and revolve the upper plate in the direction of station 2. Clamp the upper motion, and carefully center the line of sight by the upper tangent-screw. Note and record the angle upon the plate, which will be the azimuth of the line 1 2. Measure the distance from 1 to 2, and note and record the compass bearing as a check.

Now, with the upper motion securely clamped, remove the transit to station 2; and carefully center it over the stake with the north end of the plate ahead, that is, in the direction from 1 to 2. Transit the telescope, unclamp the lower motion, and bring the line of sight to cover station 1. Carefully center it by the lower tangent-screw. Clamp the lower motion, transit the telescope, unclamp the upper motion, and revolve the upper plate until the line of sight falls upon station 3, carefully centering it by the upper tangent-screw. Read and record the plate angle, which will be the azimuth of the line 2 3. Measure the distance from 2 to 3, and read the bearing of the needle for a check.

Now see that the upper plate is securely clamped, move the instrument to station 3, and proceed as before; and so on throughout the traverse.

In the above example (Fig. 80), since the first line is in the northeast quadrant, its bearing N. 38° E. will be the same as its azimuth (38°), and this angle is recorded upon the plate. The second line, however, passed into the southeast quadrant, and its azimuth will be recorded upon the plate as 38° + 81°, or 119°. Its bearing, however, will be S. 61° E. The azimuth of the third line will be 38° + 81° − 23°, or 96°. Its bearing will be S. 84° E. In a similar manner, the bearing of the fourth line may be deduced from the azimuth as shown upon the plate.

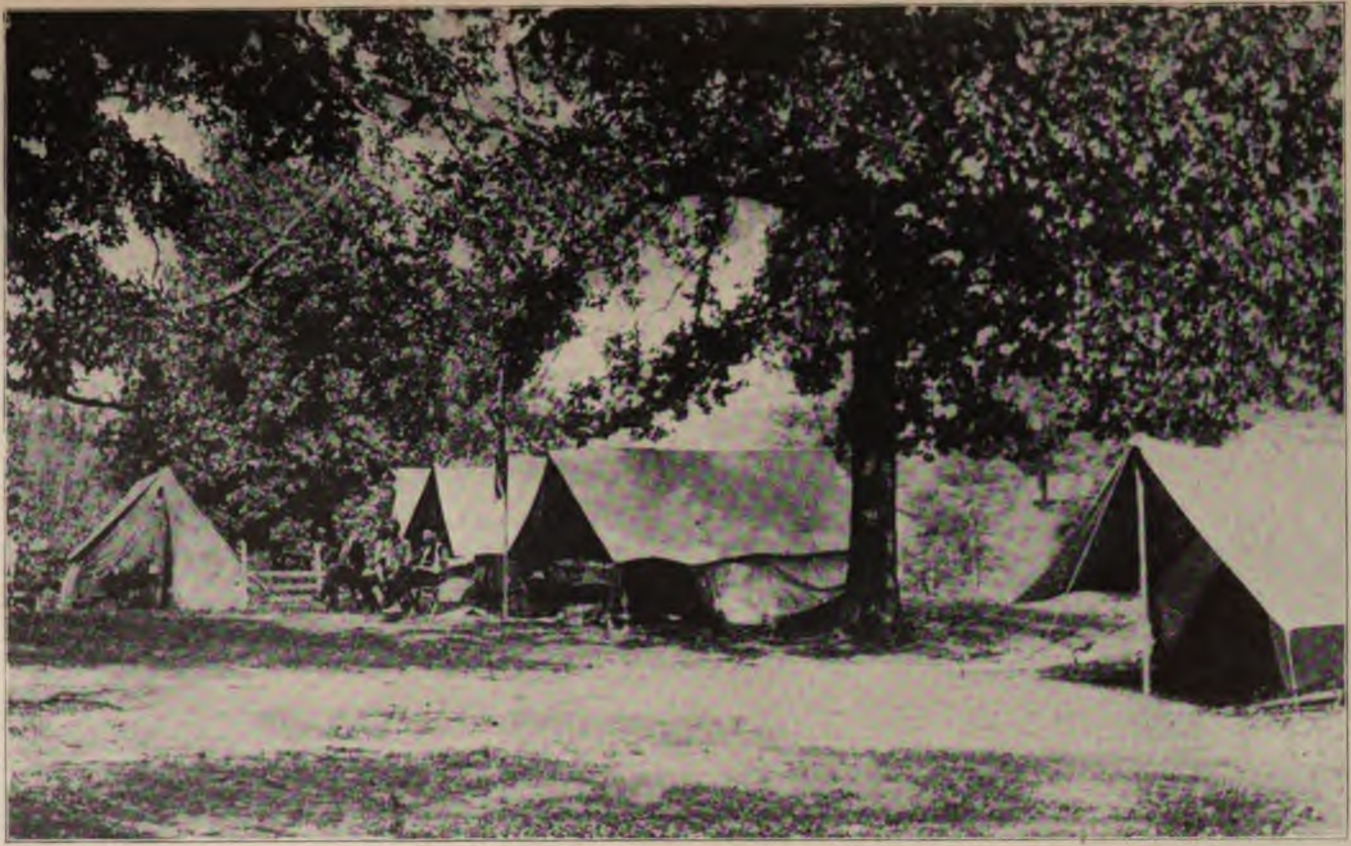
Fig. 81 illustrates a traverse beginning in the southeast quadrant. The bearing of the first line is S. 41° E., and therefore its azimuth will be 180° − 41° = 139°. The bearing of the second line will be S. 73° E., and its azimuth will be 107°; and so on with the remaining courses of the traverse.

By a similar process of reasoning, the azimuths of courses in the southwest and northwest quadrants may be deduced from the bearings, and *vice versâ*.

We therefore establish the following rules:

(*a*) Courses in northeast quadrant—Azimuth = Bearing.

(*b*) Courses in southeast quadrant—Azimuth = Supplement of Bearing.



U. S. GEOLOGICAL SURVEY CAMP IN SACRAMENTO VALLEY, CALIFORNIA

(*c*) Courses in southwest quadrant—Azimuth = 180° + Bearing.
(*d*) Courses in northwest quadrant—Azimuth = 360° Bearing.
Bearing north: Azimuth = 0° or 360°.
" east: " = 90°.
" south: " = 180°.
" west: " = 270°.

For convenience in determining azimuths, the inside graduations of the horizontal circle may be numbered from 0° to 360° to the right, beginning at the *north* end; and the outside graduations from 0° to 360° to the right, beginning at the *south* end. Then keeping the north end of the plate ahead—that is, in the direction of the traverse—for a traverse beginning in either the northeast or northwest quadrants, azimuths will be recorded directly upon the plate from the *inside* graduations; and for a traverse beginning in either the southeast or southwest quadrants, azimuths will be recorded directly upon the plate from the outside graduations.

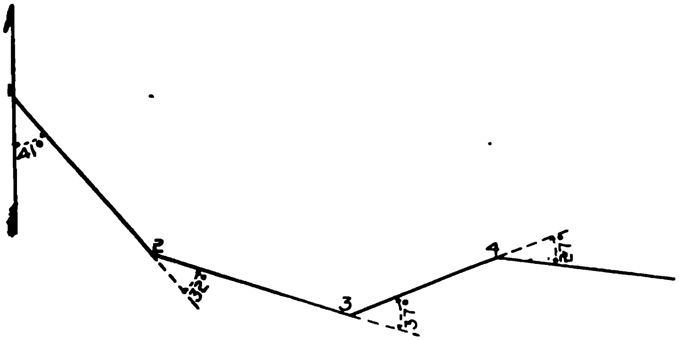


Fig. 81.

Traversing is particularly adapted to surveying roads, streets, railroads, shores of lakes, river banks, etc.; and in land surveying it possesses an advantage over the method by interior angles, on account of the readiness it affords in obtaining the bearings from the azimuths, and the greater rapidity with which the work may be platted, since the angle which each line makes with the assumed meridian or reference line, may be taken at once from the field notes.

In United States government surveys, when a traverse is run to mark the divisions between private estates and bodies of water retained as public property, it is called a *meander line*.

Keeping Notes. All notes of measurements of angles and distances should be recorded *as soon as made*, in a special notebook adapted to the purpose. Avoid the practice of making notes upon scraps of paper and in small pocket notebooks and of filling in details from memory. The notes will probably be used by other persons unfamiliar with the locality, for platting and for general information, and these persons must depend entirely upon what is recorded, and how it is recorded, for their interpretation. To this end the notes should be *clear* and *concise*, yet full enough to give all necessary information. They should permit of only one interpretation, and that the correct one.

The note keeper should bear in mind constantly the nature of the survey and the object to be attained, and this will enable him to determine what measurements are necessary. Do not crowd the notes. Use the left-hand page of the book for notes, and the right-hand page for such sketches and remarks as may be necessary. The record is usually made with a pencil, using a medium hard grade. If incorrect entries are made, erase them neatly; but avoid errors as much as possible, as too many erasures tend to discredit the work. After each notebook is filled, label it with the subject of the survey, the dates between which it was recorded, and all other information that may be of service in filing for future reference. Above all, do not lose a notebook, as it may contain information that cannot be recovered at any price.

Referring to Fig. 80, the notes would be entered in the record as follows:

STATION	DISTANCES	DEFLECTIONS		AZIMUTH	NEEDLE
		RIGHT	LEFT		
1	220.00′	38° 00′		38° 00′	N. 38° 00′ E.
2	225.00′	81° 00′		119° 00′	S. 61° 00′ E.
3	235.00′		23° 00′	96° 00′	S. 84° 00′ E.
4	190.00′		40° 00′	56° 00′	N. 56° 00′ E.

Figs. 82 and 83 illustrate the method of keeping notes by means of sketches.

Checking the Traverse. For an ordinary survey not involving unusual precision, a transit reading to single minutes will be sufficient. A single measurement will ordinarily give the angle with sufficient accuracy; but should a check upon the measurement be deemed necessary the angle may be "repeated" as explained on page 109.

As a further check against errors in angles, the magnetic bearing of each line should be read, showing the approximate directions of the lines, and by comparison with the azimuths or the deduced bearings, will serve to point out gross errors, as for instance reading right for left when measuring deflection angles. This check upon the angles should always be applied *in the field,* so that errors may be rectified before leaving the work.

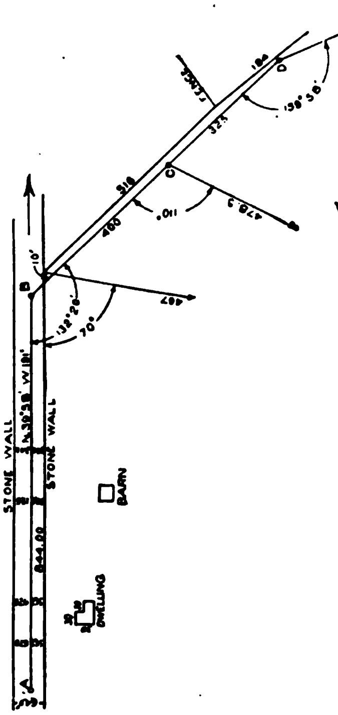


Fig. 82.

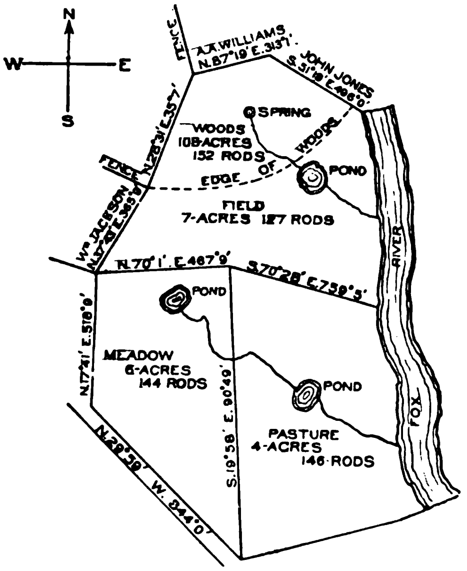


Fig. 83.

If the traverse involves a closed area, the accuracy of the transit work may be tested by adding together all of the measured angles. The sum of the interior angles should equal $(n-2) \times 180°$, n being the number of sides of the field. For the deflection angles, the sum of all the deflections to the *right* should differ from the sum of all the deflections to the left by 360°; that is to say, *the algebraic sum of the deflection angles should be* 360°.

It is sometimes desirable to check the lengths of the courses before leaving the field. If there is any reason to question the accuracy of the measurement of any line, it should be measured, preferably in the opposite direction. In a closed traverse, it is well to run diagonal lines across the traverse as an additional check upon both the angles and the measured distances.

For city work, the engineer should lay out a true meridian 300 or 400 feet long, and mark the extremities of the line by permanent monuments set in the ground and carefully protected from disturbance. To do this, in some convenient place permitting an unobstructed line of sight, drive a large stake, and mark its center by a hollow-headed tack. Center the transit carefully over this point, and proceed to lay out a true meridian, preferably with the solar attachment. Mark the direction of this line by a second stake carefully centered by a tack as before. Now, about 25 feet from the first stake, and in line with it and the second stake, excavate a hole in the ground about three feet in diameter and five feet deep, or deep enough to be below the frost line. Next build a foundation of concrete about two feet square and three feet deep. Before this has "set," insert in it a cut-stone post about nine inches square at its lower end and of such length that its top will come just below the surface of the ground, and having set into its top a copper bolt about $\frac{3}{4}$ inch by 4 inches. The post may be centered in the concrete by the transit, and should be set "plumb."

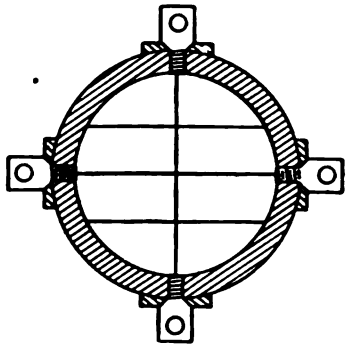


Fig. 84.

Now locate and build a second monument in line with the second stake and a few feet from it. After the concrete has set firmly, again set the transit carefully over the center of the first stake, and accurately align it by the tack in the second stake. Now "plunge" (reverse) the telescope, and carefully center a point in the top of the copper bolt; mark this point with a steel punch. In the same way center a point in the top of the bolt of the second monument. The monuments may be protected by enclosing them in cast-iron valve-boxes with covers. Either one or both of these monuments may be used as "standard" bench-marks from which all the levels and grades may be ascertained. For this purpose a city datum may be assumed, or better, the bench-mark may be connected by a line of levels with a bench-mark of the U.S. Coast and Geodetic Survey, or, if such is not available, with a bench-mark of the nearest railroad.

THE STADIA.

Attached to the diaphragm carrying the horizontal and vertical hairs, are two auxiliary horizontal hairs called "stadia" hairs or wires. These hairs may be either fixed in position or adjustable, but the fixed hairs are the better for field use and cost much less. See Fig. 84. Any instrument-maker will equip a level or a transit with either fixed or adjustable stadia wires, and they should be included in every outfit.

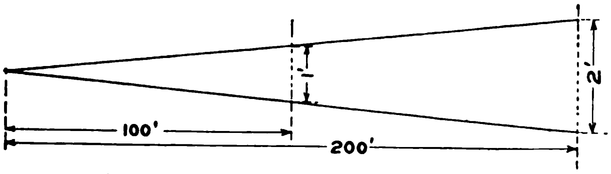


Fig. 85.

The **stadia** is used for measuring horizontal distances and differences of elevation, without the use of chain or tape or other apparatus except the leveling rod or a specially graduated stadia rod. It is based upon the principle of the similarity of triangles. Thus, if the stadia hairs are spaced so as to intercept one foot upon a rod held at a distance of one hundred feet, the rod intercept for any other distance will be in direct proportion to the first. See Fig. 85.

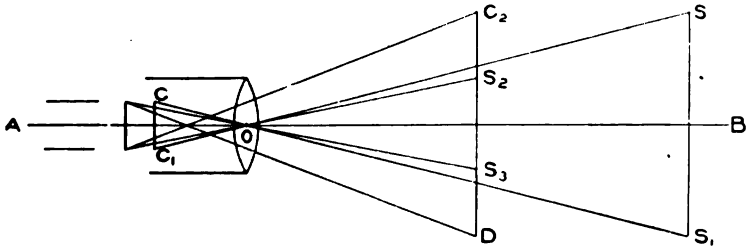


Fig. 86.

Unfortunately the construction of the telescope of an engineering instrument modifies the above simple statement, and a formula for the use of the stadia will now be deduced.

Let O in Fig. 86 be the optical center of the object-glass of the telescope. This point may be assumed at the center of the lens, and the error involved in such assumption is inappreciable and may be neglected.

. Let SS_1 be a portion of the stadia rod covered by the stadia hairs CC_1. From C and C_1 draw the lines CS_1 and C_1S through the optical center of the object-glass. Upon looking through the eye-piece of the telescope, C will be seen as at S_1 and C_1 as at S.

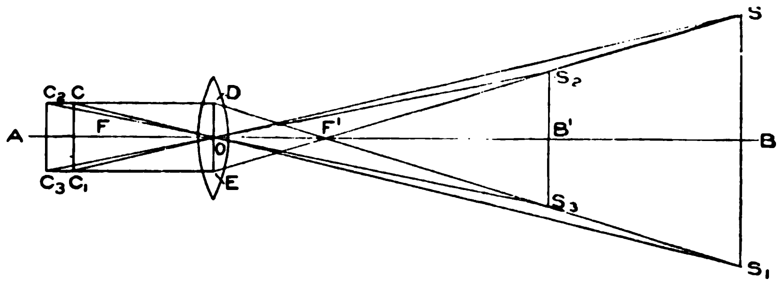


Fig. 87.

Call *i* the distance between the stadia hairs, *s* the intercept upon the rod, *f'* the distance from O to the wires, and *d* the distance of the rod from O.

The triangles COC_1 and SOS_1 are similar, and therefore we have the proportion

$$i : s :: f'' : a$$

$$\text{therefore } d = \frac{f's}{i}. \qquad (1)$$

But *f'* varies with *d*. That is to say, if the rod were to be moved closer to the instrument, as at C_2D, the lens would be moved farther from the wires, or the wires from the lens, and in either case the wire interval would intercept a shorter space upon the rod, as S_2S_3. The ratio $\frac{f'}{i}$, or its equal $\frac{d}{s}$, will therefore vary for each position of the rod. But however they vary, we have from a well-known principle of optics:

$$\frac{1}{f'} + \frac{1}{d} = \frac{1}{f}, \qquad (2)$$

in which f is the principal focal distance of the lens, and f' and d are any pair of conjugate focal distances. Substituting the value of $\frac{1}{f'}$ from (1) in (2), there results the equation

$$d = \frac{f}{i} \cdot s + f. \qquad (3)$$

Equation 3 gives the distance of the rod from the lens.

We can establish some very important relations:

In Fig. 87 lay off OF′ = OF = principal focal distance of lens $= f$.

C and C_1 being the stadia wires, draw C D and C_1 E parallel to the axis of the lens, and through F′ draw D S_1 and E S; then will S S_1 = the intercept upon the rod.

The distance of the rod from the point F′ is

$$d' = d - f = \left(\frac{f}{i} s + f\right) - f = \frac{f}{i} s.$$

From the similarity of the triangles EF′O, SF′B and S_2F′B′, we have:

$$F'O : OE :: F'B : BS :: F'B' : B'S_2.$$

Therefore the points S, S_2, F′, and E lie in the same straight line; and therefore, wherever the cross-hairs are situated, or, more strictly, whatever may be the position of the lens, the visual lines defined by the stadia wires will intercept the elements of the cone of light defined by SF′S_1.

All distances must be measured from the center of the instrument; and therefore to the expression $d = \frac{f}{i} s + f$ must be added a quantity that will represent the distance from the center of the lens to the plumb-line. This quantity is variable, of course, but an average value is usually taken. Call this quantity c. The quantity f may be found by focusing the instrument on a star, and measuring the distance from the center of the lens to the cross-hairs. We can therefore determine the quantity $f + c$. This, however, is usually supplied by the instrument-maker, and with greater precision.

The complete equation, therefore, for any distance measured with the stadia, is:

$$d = \frac{f}{i}s + (f + c) \qquad (4)$$

If, then, upon level ground we lay off the distance $f + c$ in front of the plumb-line, drive a stake, measure from this stake a distance of 100 or 200 feet, or any other convenient distance, and note the rod intercept, then in the formula $d' = \frac{f}{i}s$, d' and s are measured, and we can determine the ratio $\frac{f}{i}$; or, if f has been previously determined, we can determine the value i or the distance between the cross-hairs.

The ratio $\frac{f}{i}$ being known, distances can be found from equation 4. It is usually most convenient to make this ratio 100, so that at a distance of 100 feet the wires will intercept one foot upon the rod.

The rod may be either an ordinary leveling rod, or a stadia rod divided specially for the telescope and wires. When the rod is specially graduated, it may be in either one of two ways. Either it may be graduated so as to give the distance from F′, in which case the quantity $f + c$ will have to be added in each instance; or it may be graduated to give distances from the center directly.

If the rod is to be graduated specially, proceed as follows:

Carefully level the line of collimation of the telescope, and lay off from the plumb-line the distance $f + c$. From the point thus established measure off any convenient distance, as 500 feet, on a horizontal plane. Set up the rod, not yet graduated, at this point, and hold it carefully perpendicular to the line of sight from the telescope. This can best be done by means of a plumb-line. Be careful to eliminate all parallactic motion of the wires on the rod, when the eye is moved up and down before the eye-piece.

Mark on the rod very carefully the apparent place of the lower wire. This should be about one-quarter the length of the rod from one end if the horizontal distance first laid off is about one-half the greatest distance for which the rod can be used. The middle wire will then be at about the middle of the rod, and the upper one at about one-quarter the length of the rod from the other end.

Mark the latter point carefully. The wire interval for a space of 500 feet from F′ has thus been found. One-fifth of this space will be the wire intercept at a distance of 100 feet; twice the space, the intercept for 1,000 feet; and so on. The intermediate spaces can thus be graduated. It must not be forgotten that in using the rod thus graduated, the quantity $f + c$ must be added to the distance indicated by the rod, to reduce the distance to the center of the instrument.

If the rod is to be graduated to give distances from the center of the instrument directly, proceed as before, marking the spaces upon the rod corresponding to the distances measured upon the ground. The quantity $f + c$ will not now have to be added to the distances given by the rod; but for every point other than that for which the rod is graduated, the distance will be in error by some fractional part of $f + c$. The reason for this will be apparent by referring to Fig. 87. If the distance is less than that for which the rod was graduated, the rod readings will indicate too small a distance; and for a distance greater than the standard, the rod readings will indicate a distance too great. It is therefore more exact to mark the wire interval at 100 feet, 200 feet, and so on through the length of the rod. Each space thus determined can be divided up as desired; and the error involved in any reading will then be much smaller than if the rod were graduated for a single standard distance only.

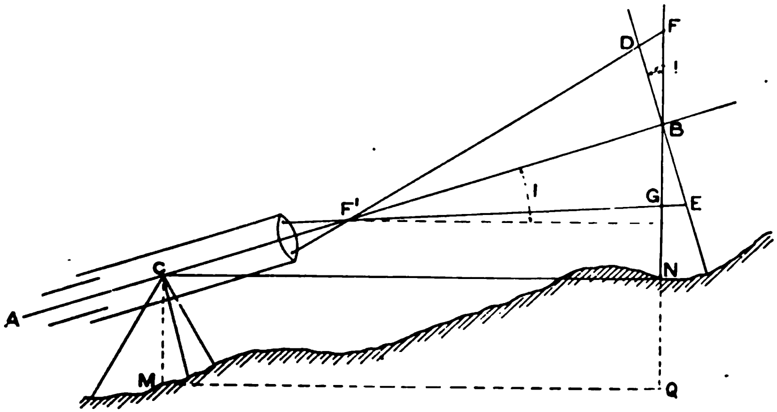


Fig. 88.

Thus far the rod has been assumed as held perpendicular to the line of sight, which of course will always be the case when using the stadia in the leveling instrument. The stadia, however, finds its greatest usefulness in connection with the transit, when the line of sight is seldom horizontal. If, at the same time the rod intercept is read, the vertical angle is noted, differences of elevation may be determined, as well as the distances.

A formula will now be deduced for reducing inclined readings to the horizontal, and for determining differences of elevation, the rod being held vertical.

In Fig. 88, let the angle of inclination of the line of sight to the horizontal plane be called B C N = F B D = I. This angle will be measured upon the vertical circle of the transit. If the rod be held perpendicular to the line of sight, the intercept upon the rod = D E = s. Represent the rod intercept when the rod is held vertical by s'. Now since the angle F D B = 90° nearly, D E = F G cos I, or $s = s' \cos I$. But $CB = \frac{f}{i} s + (f + c) = \frac{f}{i} s' \cos I + (f + c)$. Therefore the horizontal distance to the rod $= CB \cos I = \frac{f}{i} s' \cos^2 I + (f + c) \cos I = CN$. The vertical distance of the point B above the horizontal plane through the axis of the telescope $= BN = CB \sin I = \frac{f}{i} s' \cos I \sin I + (f + c) \sin I = \frac{1}{2} \frac{f}{i} s' \sin 2I + (f + c) \sin I$.

For vertical angles less than 5° the quantity $(f + c) \sin I$ is less than $0.1\,(f + c)$ and may be neglected.

The Use of the Stadia in the Field. In using the stadia wires in level country, no special instructions are necessary, as the line of sight is at all times horizontal. Over very uneven ground, the use of the level and stadia is very limited. However, there are often conditions in which the stadia wires in a leveling instrument are a very great convenience. The range of the instrument may sometimes be increased by using the center wire together with one of the stadia wires, but the instrument should be carefully tested to ascertain if the stadia wires are equally spaced with reference to the middle wire.

For extended surveys over uneven country, the transit and stadia are particularly adapted, and especially for filling in details of an extended topographical survey. The saving of time and expense are important elements in favor of the transit and stadia as compared with the transit and tape; and with a little practice and attention to details the results should be fully as accurate. Certainly, when an engineer must depend upon unskilled help to carry the tape, there can be no choice as to which to use.

For use with the stadia, the transit should be provided with a complete vertical circle, reading to minutes at least; and a level tube should be attached to the telescope. The eye-piece should be inverting. Before starting out upon a survey, the transit should be carefully tested and corrected through all of its adjustments. The field operations are then as follows:

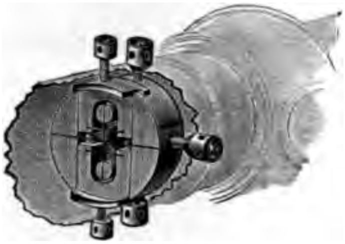


Fig. 89.

Set up the instrument over a principal station of the survey, and level it carefully. If a solar attachment is available, it will be desirable to lay out a true meridian, from which the declination of the needle may be determined. Now determine the height of the cross-hairs by holding the stadia rod close to the side of the instrument, and noting the height of the center of the horizontal axis of the telescope. Locate the second station carefully, and turn the telescope upon the horizontal axis until the center wire cuts the division upon the rod (held upon the ground) representing the height of the axis of the instrument above the ground at the first station. Now determine the azimuth of the line connecting the two stations, read the vertical angle of the telescope, and determine the rod intercept. Enter these items in the field book and proceed to take observations upon sub-stations (called "side-shots").

The same program is to be repeated for each case, except that the side-shots may or may not be taken upon points indicated by stakes. The principal stations of a stadia survey should be permanent; the stakes should be driven, and "witnessed" so as to be easily recovered.

Having now located all the necessary points from the first station, remove the instrument to the second station, and set it up with the north end of the plate in the direction of the survey. Having carefully leveled the instrument, determine the height of its axis as before, and send the rod back to the first station. Transit the telescope, and sight upon the rod as before. Read vertical angle and stadia rod, and determine azimuth, and these will serve to check the former determinations.

In moving from one station to another it is advisable to set the scale of the horizontal circle to zero. Transit the telescope again and locate the next station; and so on throughout the survey.

The principal stations of a stadia survey may have been located by a previous triangulation, in which case it will probably be necessary to locate intermediate stations as the survey progresses. Or all of the stations may be located during the progress of the survey. The courses connecting the principal stations form the "backbone" of the survey, and the azimuths and distances should be checked at every opportunity.

In keeping the field notes, represent the principal stations by triangles, as $\triangle_1$ $\triangle_2$ $\triangle_3$, etc.; and the secondary stations by circles, as $\odot_1$ $\odot_2$ $\odot_3$, etc.

Below will be found an example of the method of keeping notes. Use the right-hand page for sketches, or for such additional notes as may be necessary.

△ ⊙		H. I. 5.15		ELEV. 100.	VERT. ANGLE.	DIFFERENCE.	ELEV.
⊙	1	238	S	88° 38′ W	57′	− 3.9	96.1
⊙	2	265	S	57° 41′ W	− 58′	− 4.6	95.4
⊙	3	236	S	49° 3′ W	− 38′	— 4.6	95.4
	4	237	S	32° 58′ W	— 1° 7′	— 4.6	95.4
	5	261	S	0° 13′ W	− 1° 3′	— 4.6	95.4
△	1	425	S	44° 13′ E	— 0° 6′	− 7.5	99.25
⊙	0	H. I. 475	S	135° 41′ E			
	6	245	S	200° 23′ W	+ 1° 57′	+ 8.3	107.6
	7	300	S	204° 2′ W	+ 1° 31′	+ 7.9	101.2
	8	345	S	203° 12′ W	+ 58′	+ 5.8	105.1
△	2						

Stadia Rods. Telemeter or stadia rods are made of clear white pine well seasoned, about $\frac{7}{8}$ of an inch thick, from 4 to $4\frac{1}{2}$ inches wide, and from 10 to 16 feet long. They are protected by a metal shoe to keep the lower end from being battered or split. The rod is stiffened by having a piece 2½ inches wide along its back. Generally a stadia rod is hinged at the center for greater convenience in transportation, and at the same time it is provided with a bolt on the back to protect the graduation and to hold it in position when in use.

A self-reading level rod may be used for distances if the wires are adjustable (see Figs. 89 and 84), or if the wire interval has been determined in standard units. The rods used in connection with this grade of work differ from those employed in ordinary leveling. Those with graduations have the inner surface recessed to protect the graduated surface, and are painted white with the scale in black. The forms of graduation are different on different rods. In some, the unit of measure is the meter, while others have the foot, as will be described later. When telemeters are in use, they are open, laid flat, and held securely in line by the brass clip (or bolt) above referred to. They are sometimes provided with a target.

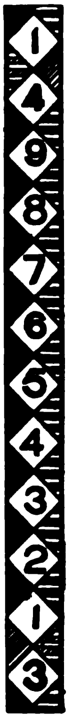


Fig. 90.

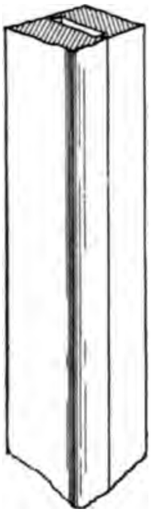


Fig. 91.

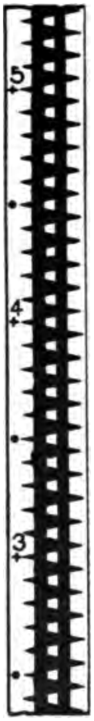
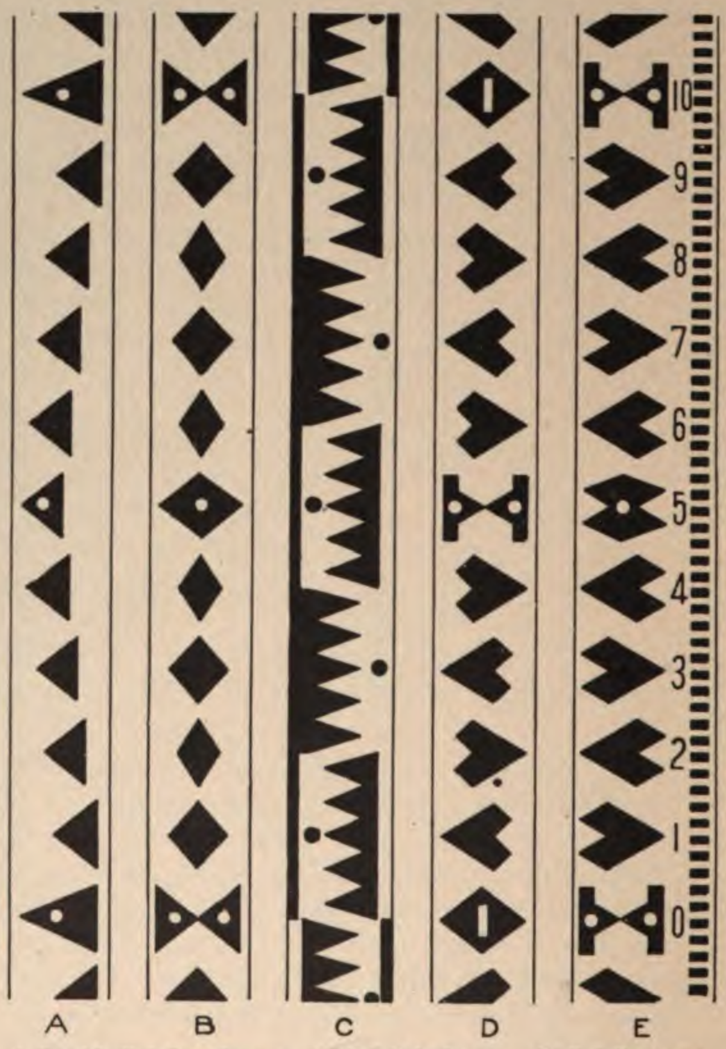


Fig. 92.

In order to have the rod held in a perfectly vertical position, a small telescope is sometimes attached to its side, by means of



A, B and C—U. S. Coast Survey. D—U. S. Lake Survey. E—U. S. Engineers.

Fig. 93.

which the rodman can tell whether the rod is in a vertical plane.

Figs. 90 and 93, D, show two types of graduations suitable where the meter is the unit. Fig. 93, D, has for many years been used by the United States Coast and Geodetic Survey as well as by the United States Lake Survey. The angles of graduation divide the rod into two centimeter intervals. Fig. 90 shows the rod used on the survey of the Mexican border. The graduation is apparent, and no further explanation need here be given.

Figs. 92 and 93, C, are types suitable where the foot is the unit. In Fig. 92 the width comprised between the ends of the points divide into five equal parts, the vertical black lines taking up two of these differences. The diagonal then gives one hundredth of a foot, and permits readings direct to single feet. Fig. 91 shows a plain rod without scale, and the unit is the foot. Classes A, B, C, D and E, Fig. 93, belong to the respective surveys as indicated.

TIME OF ELONGATION AND CULMINATION OF POLARIS.

DATE IN 1899.		EAST ELONGATION.		UPPER CULMINATION.		WEST ELONGATION.		LOWER CULMINATION.	
		h.	m.	h.	m.	h.	m.	h.	m.
January	1	0	41.9	6	36.7	12	31.5	18	34.7
	15	23	42.7	5	41.7	11	36.2	17	39.4
February	1	22	35.5	4	34.3	10	29.1	16	32.3
	15	21	40.3	3	39.0	9	33.9	15	37.0
March	1	20	45.1	2	43.6	8	38.6	14	41.8
	15	19	50.0	1	48.8	7	43.5	13	46.8
April	1	18	43.0	0	41.7	6	36.5	12	39.8
	15	17	48.0	23	42.8	5	41.5	11	44.8
May	1	16	45.2	22	39.9	4	38.7	10	41.9
	15	15	50 3	21	45.0	3	43.8	9	47.0
June	1	14	43.6	20	38.4	2	37.1	8	40.4
	15	13	48.7	19	43.5	1	42.2	7	45.5
July	1	12	46.1	18	40.9	0	39.6	6	42 9
	15	11	51.2	17	46.0	23	40.8	5	48.0
August	1	10	44.7	16	39.5	22	34.3	4	41.5
	15	9	49.8	15	44.6	21	39.4	3	46.6
September	1	8	43.2	14	38.0	20	32.8	2	40.0
	15	7	48.3	13	43.1	19	37.9	1	45.1
October	1	6	45.5	12	40.3	18	35.1	0	42.3
	15	5	50.5	11	45.3	17	40.1	23	43.4
November	1	4	43.7	10	38.5	16	33.3	22	36.5
	15	3	48.5	9	43.3	15	38.1	21	41.3
December	1	2	45.5	8	40.3	14	35.1	20	38.3
	15	1	50.2	7	45.0	13	39.8	19	43.0

AZIMUTH OF POLARIS AT ELONGATION.

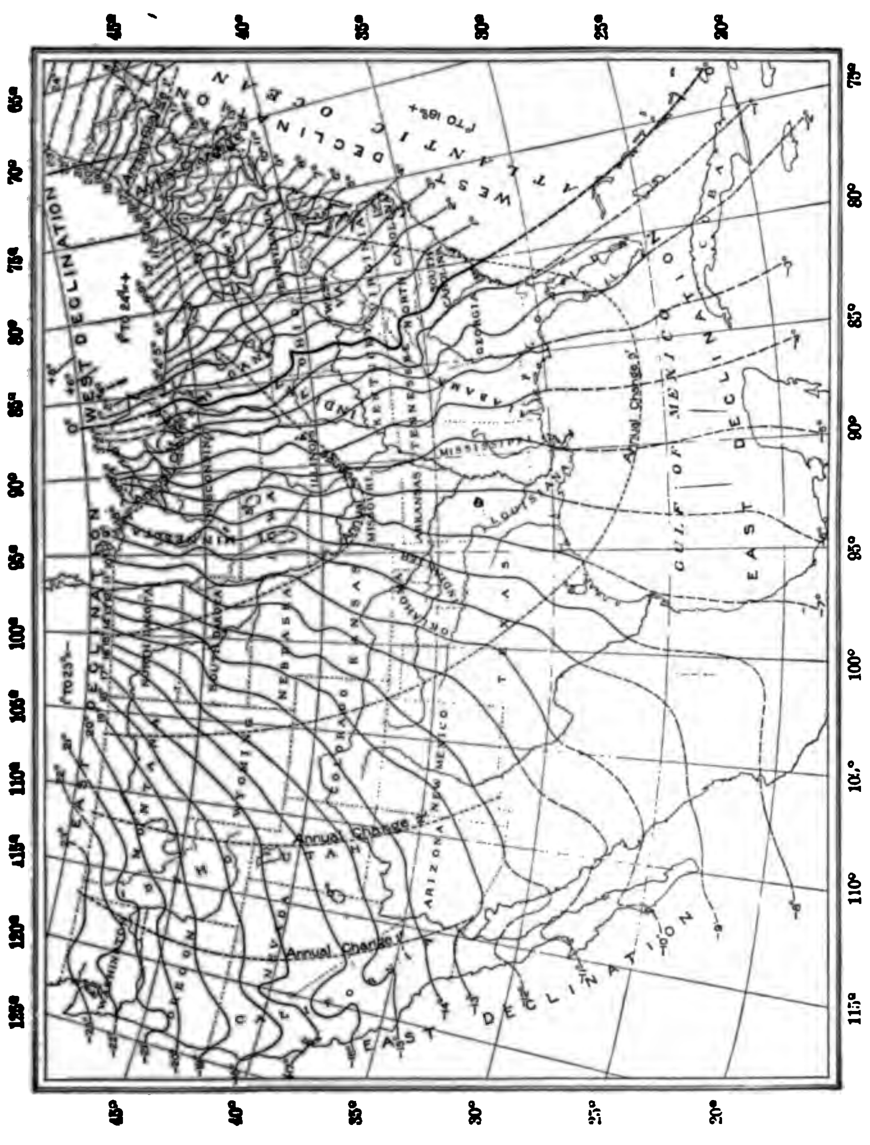
YEAR.	25°	30°	35	40	45	50°	55°
1900	1° 21′ .2	1° 24′ .9	1° 29′ .8	1° 36′ .0	1° 44′ .0	1° 54′ .4	0° 08′ .3
1901	1 20 .8	1 24 .6	1 29 .4	1 35 .6	1 43 .6	1 54 .0	2 07 .8
1902	1 20 .5	1 24 .2	1 29 .0	1 35 .2	1 43 .2	1 53 .5	2 97 .2
1903	1 20 .1	1 23 .9	1 28 .7	1 34 .8	1 42 .7	1 53 .0	2 06 .6
1904	1 19 .8	1 23 .5	1 28 .3	1 34 .4	1 42 .3	1 52 .5	2 06 .1
1905	1 19 .4	1 23 .1	1 27 .9	1 34 .0	1 41 .8	1 52 .0	2 05 .6
1906	1 18 .4	1 22 .1	1 26 .8	1 32 .8	1 40 .5	1 50 .0	2 05 .0
1907	1 18 .7	1 22 .4	1 27 .1	1 33 .2	1 40 .9	1 51 .0	2 04 .4
1908	1 19 .4	1 22 .1	1 26 .8	1 32 .8	1 40 .5	1 50 .6	2 03 .9

Calumet-Sag Canal Survey. Sanitary District of Chicago.

Triangulation Station, Irrigation Survey, Hawaiian Islands.

TRANSITMEN AT WORK IN THE FIELD

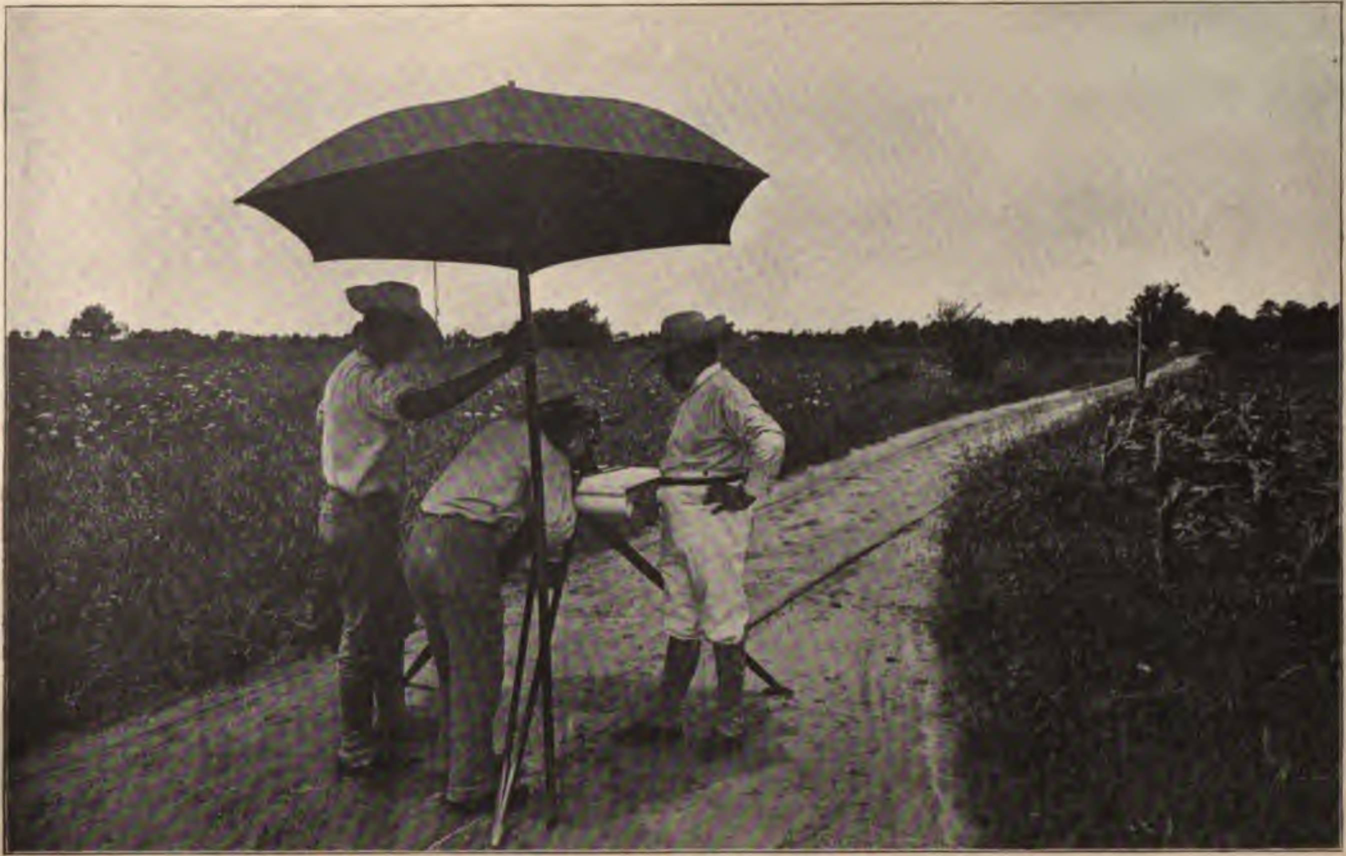
Courtesy of R. Isham Randolph.



UNITED STATES GEODETIC SURVEY

Base Map of the United States

Declinations west of the line of zero declination are —, those east are +.



RUNNING A TRAVERSE LINE

In doing this work, the surveying party may for a while lose sight of all signal points. Station points marked by the forward rodman (shown in the distance) are selected at short intervals and accurately located. The rear rodman (not seen in the picture) is standing over the station just left.

PLANE SURVEYING.

PART III.

THE GRADIENTER.

The vertical circle or arc of the transit or theodolite, under ordinary circumstances, furnishes the means of measuring the vertical angle through which the line of collimation is turned, or, on the other hand, of turning the line of collimation through any desired vertical angle. Much of the work of the engineer consists in measuring slopes or grades, or in setting a line at a certain slope or grade; and the data are given, not in terms of the vertical angle directly, but usually by the amount of rise or fall per 100 feet. Thus, a rise or fall of 2 feet in 100 feet is designated as a 2 per cent grade; a rise or fall of 50 feet to the mile would be designated as a 0.95 per cent grade, etc. The ratio of these two quantities, *rise* (or *fall*) to *reach* is evidently the natural tangent of the angle of slope; and before the vertical circle can be used for setting off such slopes, the ratio must be transformed into degrees and minutes of arc.

The tangent-screw of the horizontal axis of the telescope, without the aid of the vertical circle, provides the means of quickly and accurately setting off slopes directly, when the vertical angle does not exceed fifteen or twenty degrees. For this purpose, the ordinary tangent-screw is replaced by a fine screw, with very uniform pitch and large graduated head, and also a graduated scale from which may be read the number of turns or double turns made by the screw. The graduated head fits friction-tight upon the neck of the screw, so that its index may be made to read zero when the line of collimation is horizontal; and it is usually divided into fifty parts, so that, after the number of double turns is read from the scale, it will give the number of fiftieths of a single turn, or hundredths of a double turn. (See Fig. 94.)

Let the distance of the screw from the axis about which the telescope turns, be represented by l and the interval between

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the threads by t. If the screw is turned through one revolution, the lever AD (Fig. 94) is moved through the distance DE, and the line of collimation through the distance BC, upon the rod PQ. Now, the tangent of the angle DAE $= \frac{DE}{AD} = \frac{BC}{AB} = \frac{t}{l}$. To this ratio, the maker of the instrument can give any convenient value, but it is customary to make it $= \frac{1}{200}$, and it will be so considered throughout this discussion.

If, then, the line of collimation be directed toward the graduated rod PQ, the space over which the line of collimation is moved for one revolution of the screw is $\frac{1}{200}$ of the distance of the rod from the instrument; and the space upon the rod over which it is moved for two revolutions of the screw $= \frac{2}{200} = \frac{1}{100}$ of the above distance. If the screw is turned through less than a single revolution, it will be indicated upon the graduated head, as, for instance, $\frac{35}{50}$ of a single turn, the intercept upon the rod being $\frac{7}{10} \times \frac{1}{200} = \frac{7}{2,000}$ of the distance from rod to instrument—it being understood, of course, that the rod is held perpendicular to the line of collimation in its initial position. The index of the graduated head should read zero when the line of collimation is horizontal, and the reading of the scale of revolutions should be zero at the same time.

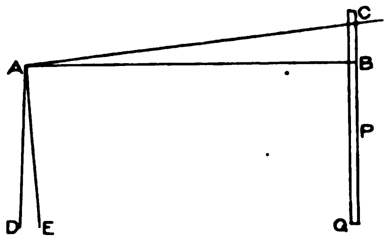


Fig. 94.

The gradienter may be used as a telemeter, as a level, or simply as a grade-measurer, as will be explained in what follows.

Call s the intercept upon the rod for any movement of the gradienter-screw, and d the distance from the instrument to the rod.

If the number of revolutions of the gradienter-screw is known, whether s and d are known or not, the tangent of the angle of inclination of the line AC is known, and the instrument is a grade-measurer or gradienter.

If the space *s* and the number of revolutions of the gradienter-screw are known, the distance *d* is known, and the instrument is then a telemeter.

If the distance *d* and the number of revolutions of the gradienter-screw are known, the space *s* is known, and the instrument then serves the purpose of a level.

As a gradienter, the instrument may be used either to measure the grade of a given line, or to lay out a line to a required grade.

(1.) Let AB (Fig. 95) be the line whose grade is required. Set the transit up over the point A, and level carefully. Measure the height of the cross-hairs above the ground by holding the rod beside the instrument and noting the point upon the rod directly opposite the center of the horizontal axis of the telescope. Bring the line of collimation CE horizontal by means of the bubble attached to the telescope (the instrument is supposed to be in adjustment), and set both the indexes to zero. Now carry the rod to the point B, and by means of the gradienter-screw turn the telescope in a vertical plane until the line of collimation strikes the point D as far above B as C was above A. Now count the number of full turns from the reading of the scale by the screw-head, and the number of fractions of a turn from the divided head. The former will give the rise (or fall) in *feet* per 100, and the latter in hundredths of a foot. It must be remembered that if the screw has made more than a whole turn past the last number on the scale the reading of the head must be increased by fifty.

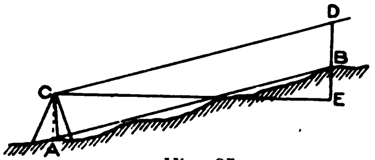


Fig. 95.

Thus, if the reading of the scale is 3 and the reading of the head is 35, plus one whole revolution, the rise (or fall) per 100 feet will be as follows:

3	*double* turns - - - - -	3.00 ft.
1	*single* turn - - - - -	0.50 ft.
$\frac{35}{50}$	" " - - - - -	0.35 ft.
		3.85 ft.

So that the slope of CD, which equals that of AB, is therefore 3.85 per cent.

EXAMPLE FOR PRACTICE.

If the scale reads 2 and the head 31, determine the percentage of slope.

(2.) It is required to lay out in a given direction a line with a given percentage of slope from the point A. See Fig. 96.

Set up the instrument on the given point, as B, and level it carefully. Measure the height of the cross-hairs above the ground as before, and set the pointers to read zero with the bubble in the center of the telescope tube. Now revolve the line of collimation in a vertical plane by means of the gradienter-screw so as to set off the required slope. For instance, suppose it is required to set off a slope of 2.78 per cent. The screw should be turned five complete revolutions as indicated upon the scale, plus $\frac{28}{50}$ of a revolution as indicated upon the divided head of the screw:

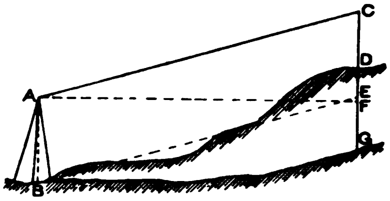


Fig. 96.

$$\frac{5}{200} \times 100 \text{ ft.} = 2.50 \text{ feet.}$$

$$\frac{28}{50} \times \frac{1}{200} \times 100 \text{ ft.} = 0.28 \text{ feet}$$

$$= 2.78 \text{ feet per } 100 \text{ feet.}$$

Now carry the rod to any convenient point, as G, in the direction of the required line; hold it in a vertical position; and note the height of the line of collimation. Take the difference between this and CE (= AB). If this difference, as EG, is positive, it gives the height of the grade line *above* the ground and indicates a *fill* at the point. If the difference is negative, as DE, it gives the depth of the grade line *below* the ground and indicates a *cut.*

EXAMPLE FOR PRACTICE.

Let it be required to set off a 3.35 per cent grade, and describe the operation in detail.

When the gradienter is used as a telemeter, it may be upon level or sloping ground.

(1.) *Upon Level Ground.* Set up the transit at one end of the line, and level carefully. Bring the bubble of the telescope level to the center of its tube, and both gradienter scales to zero.

Now send the rod to the next station and let it be held vertical; adjust the target to the line of collimation and take the reading. Now turn the gradienter-screw through two revolutions and take the reading again (see Fig. 97). The difference of the two readings gives DE in feet; and since the gradienter-screw has been turned through two revolutions, CE = 100 DE. Thus, if DE = 3.25 feet, CE = 325 feet.

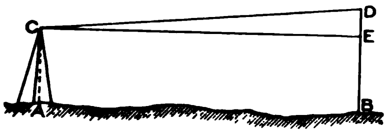


Fig. 97.

(2.) *Upon Sloping Ground.* On sloping ground the first reading upon the rod cannot be taken with the telescope horizontal, but the telescope must be revolved in a vertical plane until the intersection of the cross-hairs falls at a division upon the rod equal to the height of the cross-hairs above the ground at the transit station. If now the rod be held perpendicular to the line of sight, and the gradienter-screw turned through two revolutions, the intercept upon the rod will be $\frac{1}{100}$ of the required distance. With the gradienter, as with the stadia, it is more convenient to hold the rod vertical and apply the necessary correction to the rod reading.

Set up the transit over a point at one end of the line and level carefully. Measure the height of the cross-hairs above the ground. Now loosen the clamp of the tangent-screw attached to the vertical arc or circle, and revolve the telescope in a vertical plane until the intersection of the cross-hairs falls upon a point C (Fig. 98) upon the rod held at D, such that CD = AB. Read and note the vertical angle after clamping the gradienter-screw with both scales set to read zero. This angle will be θ (Fig. 98). Now turn the gradienter-screw through two revolutions, and note the reading ED upon the rod; the difference between this and CD (= AB) will give EC, which call S′; let FC, the perpendicular intercept upon the rod, be called S; the distance AC, parallel to the slope, H′; and let the horizontal distance AG be denoted by H. Then from the figure,

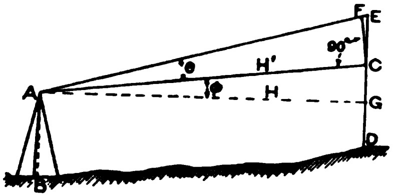


Fig. 98.

$$H' = 100\, S.$$

Now, from the right triangle EAG, the angle at E $= 90° - (\theta + \phi)$; and from the right triangle FAC, the angle at F $= 90° - \theta$. Therefore, in the triangle CFR, the angle at F $= 180° - (90° - \theta) = 90° - \theta$.

Therefore,

$$S : S' :: \sin [90 - (\theta - \phi)] : \sin (90 + \theta);$$

$$\text{or } S : S' :: \cos (\theta - \phi) : \cos \theta.$$

$$\text{Hence } S = S' \frac{\cos (\theta - \phi)}{\cos \theta}$$

$$= S' \frac{\cos \theta \cos \phi - \sin \theta \sin \phi}{\cos \theta} = S' (\cos \phi - \sin \phi \tan \theta);$$

but $\tan \theta = \frac{1}{100}$, and therefore $S = S' (\cos \phi - \sin \phi \frac{1}{100})$.

Therefore H', the distance along the slope,

$$= S' (100 \cos \phi - \sin \phi);$$

and H, the horizontal distance,

$$= H' \cos \phi = S' (100 \cos^2 \phi - \cos \phi \sin \phi)$$

$$= S' (100 \cos^2 \phi - \tfrac{1}{2} \sin 2 \phi)$$

$$= 100\, S' - S' (100 \sin^2 \phi + \tfrac{1}{2} \sin 2 \phi).$$

It may be well to note that the lower reading of the rod need not necessarily be such as to make CD = AB, but only as a matter of convenience.

EXAMPLE FOR PRACTICE.

Upper rod reading = 7.49

Lower rod reading = 4.67

Vertical angle of lower rod reading = 15° 35'.

Required to find the distance parallel to the slope between B and D and the horizontal distance AG.

Let it now be required to find the difference of elevation between B and D = CG.

Evidently $CG = H \tan \phi = S' (100 \cos^2 \phi \tan \phi - \cos \phi \sin \phi \tan \phi)$.

$$= S' (100 \sin \phi \cos \phi - \sin^2 \phi)$$

$$= S' (100\, \tfrac{1}{2} \sin 2 \phi - \sin^2 \phi).$$

In the last example, determine the difference of level of B and D.

It must not be forgotten of course, that the gradienter used in this way cannot give results so accurately as the spirit level;

but nevertheless, for rapid work, the results will be sufficiently correct.

If the student possesses a set of stadia reduction tables, the values of $\sin^2 \phi$ and $\frac{1}{2} \sin 2 \phi$ can be taken out at once and much labor saved.

To Lay out a Meridian with the Transit. *By means of the North Star at Upper or Lower Culmination.* Twice in 24 hours (more exactly, 23 hours 56 minutes) the north star "culminates"; that is to say, it attains to its maximum distance from the pole, above or below it. At the moment of culmination, the star is upon the meridian and if, therefore, a line be ranged out upon the ground in the same vertical plane, it will define a meridian.

Set up the transit over a peg, in an open space, giving an unobstructed view of a line about 400 or 500 feet long. Level the instrument carefully (it should be in perfect adjustment), and, a few minutes before the time of culmination, as given in the table, focus the intersection of the cross-hairs upon the star; clamp the plates, the vertical axis, and the horizontal axis of the telescope. Now by means of the tangent-screws attached to the vertical axis and to the vertical circle, move the telescope in azimuth and altitude, keeping the cross-hairs fixed upon the star. After a time it will be found that the position of the star no longer changes in altitude; it is then upon the meridian. Now clamp the vertical axis, plunge the telescope, and carefully center a stake 400 or 500 feet from the instrument; the line connecting the two stakes, will define the true meridian.

The whole operation may be repeated several nights in succession, and the mean of all the results taken.

By Means of the North Star at Eastern or Western Elongation. Twice in 24 hours, the north star attains to its maximum distance east or west of the pole, called its eastern or western "elongation." If a line be ranged out upon the ground in the direction of the star—at, say, the time of eastern elongation, and again at the time of western elongation—and if the angle between these two lines be bisected by a third line, this last line will evidently be a true north and south line.

Otherwise. Having laid out a line upon the ground in the direction of the north star—say at western elongation—take from a table the azimuth (or bearing) of the star at such time, and upon the horizontal plate of the transit set off this angle to the east and range out a line—which will therefore be a true north and south line. If the position of the star is taken at eastern elongation, the azimuth must be turned off to the west.

Set up the transit over a peg a few minutes before the star attains its maximum elongation, as given by the table. Level, and fix the line of collimation upon the star, following its movement as described under the previous method. After a time, it will be found that the movement of the star in azimuth ceases; the star has then attained its maximum elongation. Now clamp the vertical axis of the instrument, plunge the telescope, and center a stake in the proper direction. Now take from the table the proper azimuth, revolve the upper plate through the given angle in the proper direction, and range out a line upon the ground for the true meridian.

In order to determine the azimuth of the north star at eastern or western elongation, it is necessary to know the latitude of the place of observation.

Definitions. The **altitude** of a star is the vertical angle at the instrument included between the plane of the horizon and the line from the instrument to the star, as given by the line of collimation.

The **latitude** of a place is equal to the altitude of the pole.

If, therefore, we have any method of determining the altitude of the pole, the latitude of the observer is known at once.

The altitude of the pole may be determined by observing the altitude of the north star, first at its upper culmination and again at its lower culmination. The mean of these observations, corrected for refraction, will give the altitude of the pole and therefore the latitude of the observer. See tables of refraction of Polaris.

Set up the transit and level it, and proceed in the same manner as described under the first method for laying out a true meridian. When the star has reached its maximum distance above or below the pole, as indicated by the line of collimation moving in a horizontal plane, clamp the horizontal axis of the telescope and read the angle upon the vertical circle. The result will be the altitude of the star, say at upper culmination. Repeat the operation at lower culmination. Now, if A represents the altitude at upper culmination, and A_1 the altitude at lower culmination; d the refraction at upper culmination, and d_1 the refraction at lower culmination, then A_p, the altitude of the pole (= latitude of the place), will be given by the following:

$$A_p = \frac{1}{2}(A + A_1 - d - d_1)$$

It will be well to repeat these observations and take the mean of the results as the probable altitude of the pole.

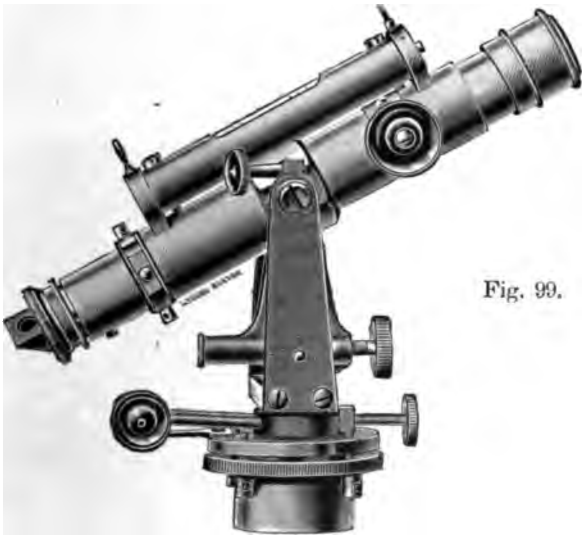


Fig. 99.

THE SOLAR TRANSIT.

The solar transit is an ordinary engineer's transit fitted with a solar attachment. Of the many forms of solars in use, that invented by G. N. Saegmuller, Washington, D. C., seems to be the favorite. In its latest form it is shown in Fig. 99, and consists of a telescope and level attached to the telescope of the transit (see Fig. 100) in such a manner as to be free to revolve in two directions at right angles to each other. When the transit telescope is horizontal and the bubble of the solar in the center of its tube, the auxiliary telescope with its bubble revolves in horizontal and vertical planes.

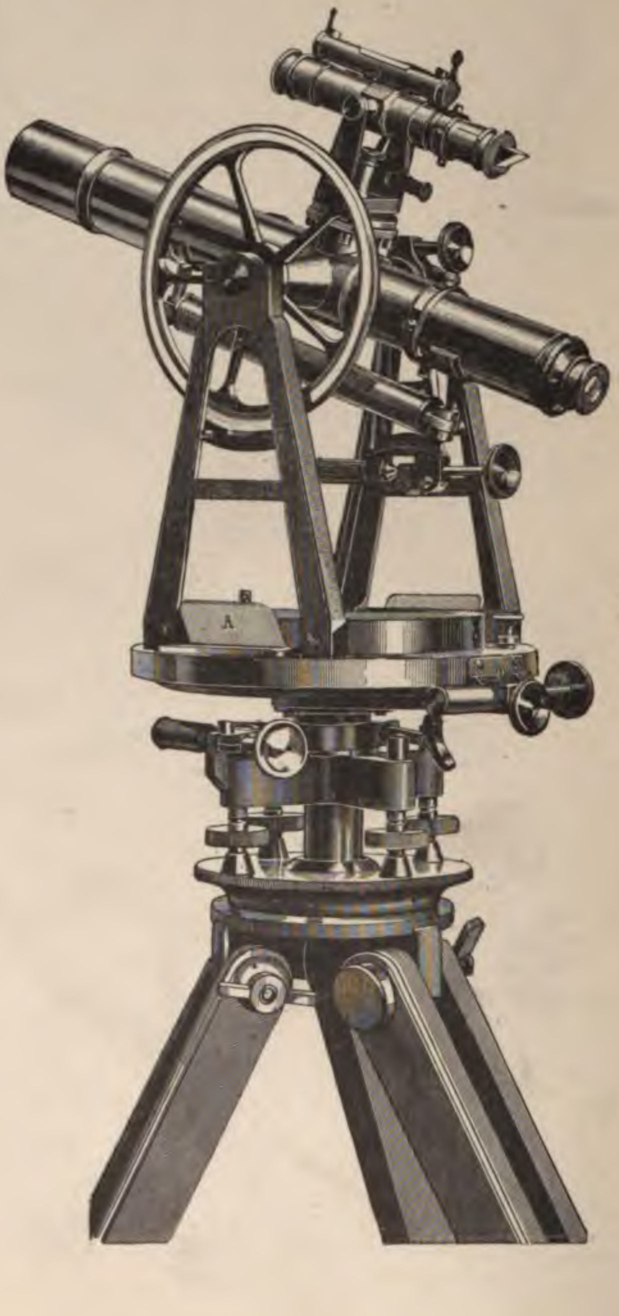


Fig. 100.

If now the line of collimation of the transit be brought into the meridian, the telescope pointing to the south, then, if we lay off upon the vertical circle, upward, the co-latitude of the place, the polar axis of the solar will be parallel to the axis of the earth. If now the two lines of sight are parallel and the solar telescope is revolved upon its polar axis, it is evident that its line of sight will describe a plane parallel to the plane of the equator. If now the transit telescope be still maintained parallel to the equator, if we turn the solar telescope upon its horizontal axis until the angle between the two lines of collimation equals the declination of the sun, then when the solar telescope is revolved upon its polar axis, its line of collimation will follow the path of the sun for the given day, provided there be no change in the sun's declination. If therefore the solar telescope is revolved until the image of the sun is brought between a pair of horizontal and vertical wires, provided in the telescope for that purpose, at that instant the line of sight of the transit telescope is in the meridian.

The horizontal axis of the solar telescope and the polar axis of the solar are provided with clamps and tangent-screws by means of which careful adjustments may be made. Two pointers are attached to the solar telescope, so adjusted that when the shadow of the one is thrown upon the other, the sun will appear in the field of view. There are also provided colored glass shades to the eyepiece to protect the eye when observing upon the sun. The objective and the cross-hairs are focused in the usual way.

Adjustments of the Solar Transit. It is assumed in what follows that the transit is in perfect adjustment, particularly the plate levels, the horizontal axis of the telescope, and the zero of the vertical circle.

1. *To adjust the Polar Axis.* The polar axis should be vertical when the line of collimation and the horizontal axis of the telescope are horizontal. To make this adjustment, level the transit by means of the plate levels. If the telescope is not fitted with a level, make the vernier of the vertical circle read zero. Now bring the bubble of the solar to the center of its tube and clamp the horizontal axis. Loosen the clamp of the polar axis, and turn the solar upon its polar axis through 180°. If the bubble remains in the center of the tube, the solar axis is in adjustment. If the

bubble runs toward one end of the tube, correct one-half of the error by revolving the solar telescope upon its horizontal axis and the other half by means of the capstan-headed screws at the base of the solar.

If the telescope of the transit is fitted with a level, it will be better to test the verticality of the vertical axis by means of it, since it is longer and more sensitive than the bubbles upon the plate. To do this, revolve the telescope upon its vertical axis until it is directly over a pair of diagonally opposite plate screws, and bring the bubble to the center by means of the tangent-screw attached to the horizontal axis of the telescope. Now revolve the telescope upon its vertical axis through 180°, and note if the bubble runs to one end; if it does correct one-half the error by the parallel plate-screw and the other half by the tangent-screw of the horizontal axis, and repeat this test and correction until the bubble remains in the center in all positions.

2. *To Adjust the Cross-Hairs of the Solar.* The line of collimation of the solar telescope should be parallel to the line of collimation of the transit telescope. The first adjustment having been made, first bring the telescope into the same vertical plane by centering a stake by the transit telescope and clamping the vertical axis. Now turn the telescope of the solar upon the polar axis until the intersection of the cross-hairs covers the same point upon the stake, and clamp the polar axis. Now level both telescopes by bringing the bubbles to the center, and measure the distance between the axes of the two telescopes; draw at this distance two black parallel lines upon a piece of white paper. Tack up the paper against a wall, post, or other convenient object, adjusting it in position so that one black line is covered by the horizontal cross-hair of the transit telescope; notice if the other black line is covered by the horizontal cross-hair of the solar; if so, the adjustment is completed; otherwise, move the diaphragm carrying the cross-hairs of the solar, until the second black line is covered. Adjusting the cross-hair diaphragm may displace the solar telescope vertically, so that the bubble should again be brought to the center of the tube, and the adjustment tested and repeated until the two lines of collimation are parallel, when the two bubbles are simultaneously in the center of the tubes.

The Use of the Solar Transit. An observation with the solar transit involves four quantities as follows:

1. The time of day, that is to say, the hour-angle of the sun.
2. The declination of the sun.
3. The latitude of the place of observation.
4. The direction of the meridian.

Any three of these quantities being known, the fourth may be determined by direct observation. The principal use of the solar transit is to determine a true meridian when the other three quantities are known.

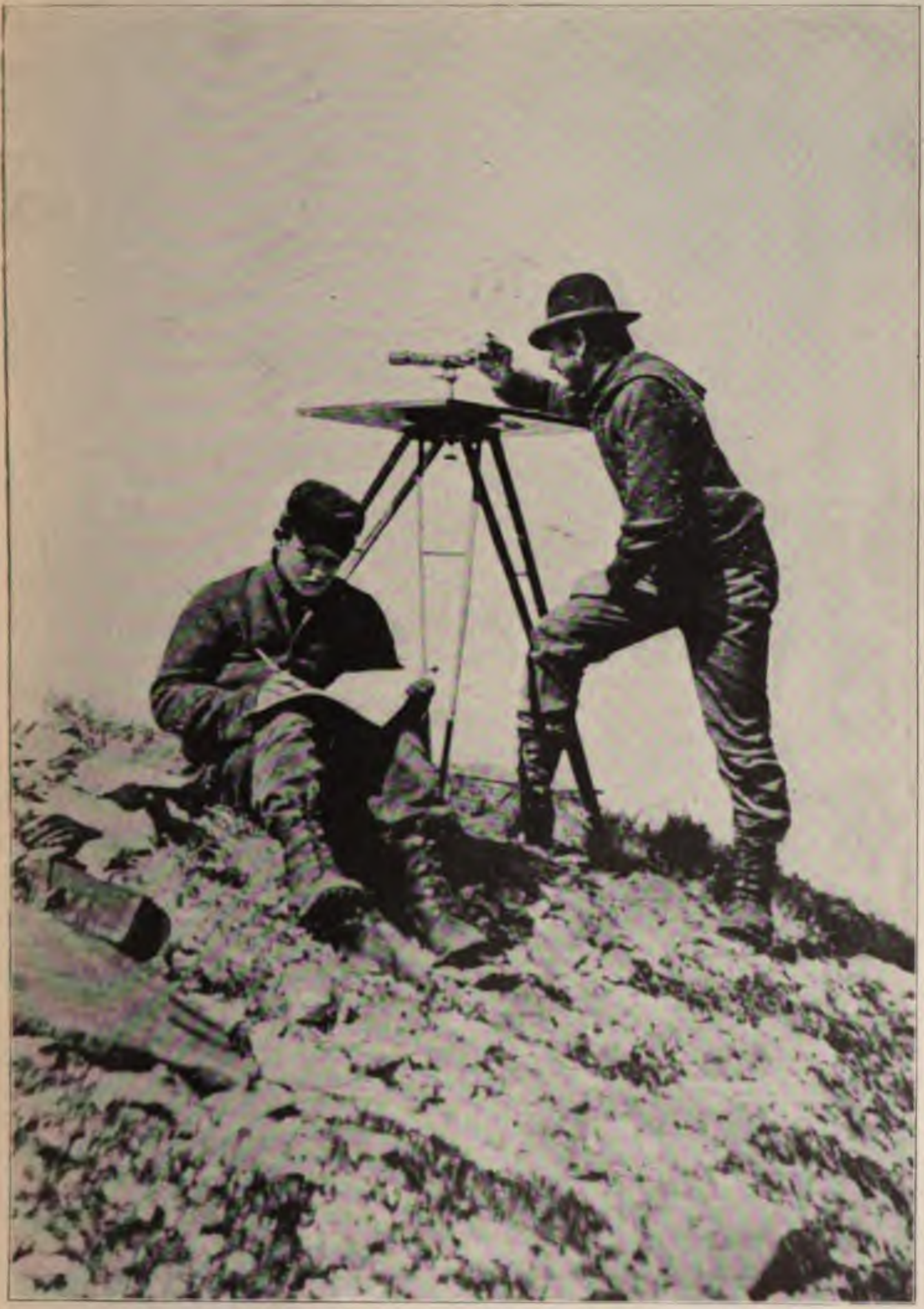
To Lay Out a True Meridian. Set up the transit over a stake; level the instrument carefully; and bring the lines of collimation of the telescopes, into the same vertical plane by the method previously described. Take the declination of the sun as given in the *Nautical Almanac* for the given day, and correct it for refraction and hourly change. Revolve the *transit telescope* upon its horizontal axis so that the vertical circle will record this corrected declination, turning it down if the declination is north, and elevating it if the declination is south. Now, without disturbing the position of the transit telescope, bring the solar telescope to a horizontal position by means of the attached level. It is evident that the angles between the lines of collimation will equal the corrected declination of the sun, and the inclination of the solar telescope to its polar axis will be equal to the polar distance of the sun.

Next, without disturbing the *relative* positions of the two telescopes, set the vernier of the transit telescope to the co-latitude of the place, and clamp the horizontal axis. It is evident that the transit telescope is parallel to the equator, and that the solar telescope is in a position to describe the path of the sun when the line of collimation of the transit *is in the true meridian*; and unless the line of collimation is in the true meridian, the sun cannot be brought between the cross-hairs of the solar telescope. Therefore unclamp the vertical axis of the transit and the polar axis of the solar, and, maintaining the *relative* positions of the telescopes revolve the transit upon its vertical axis, and the solar upon its polar axis, until the sun is brought between the cross-hairs of the solar telescope. Now clamp the vertical axis of the transit and range out a line upon the ground for the true meridian.

The solar apparatus should not be used between 11 A. M. and 1 P. M. if the best results are desired. From 7 to 10 A. M. and from 2 to 5 P. M. in the summer will give the best results. The greater the hour-angle of the sun, the better the observation will be so far as instrumental errors are concerned. However, if the sun is too close to the horizon, the uncertainties in regard to refraction will cause unknown errors of considerable magnitude.

Observation for Time. If the two telescopes—being in position, one in the meridian and the other pointing to the sun—are now revolved upon their *horizontal* axes (the vertical remaining undisturbed) until each is level, the angle upon the horizontal plate between their directions, as found by sighting on a distant object, will give the time from apparent noon, reliable to within a few seconds.

To Determine the Latitude. Level the transit carefully, and point the telescope toward the south, setting off the declination of the sun upon the vertical circle, elevating the object end if the declination is south, and depressing it if the declination is north. Bring the telescope of the solar into the same vertical plane with the transit telescope by the method previously described, level it carefully, and clamp it. The angle between the lines of collimation will then equal the declination of the sun. With the solar telescope, observe the sun a few minutes before its culmination, by moving the *transit telescope in altitude and azimuth* until the image of the sun is brought between the cross-hairs of the solar, keeping it there by means of the tangent-screws until the sun ceases to rise. Then take the reading of the vertical circle, correct for refraction due to altitude by the table below, subtract the result from 90°, and the remainder is the latitude sought.



TOPOGRAPHERS OF U. S. GEOLOGICAL SURVEY AT WORK ON MOUNTAIN SUMMIT IN ALASKA

Mean Refraction at Various Altitudes.*

Barometer, 30 inches. Fahrenheit Thermometer, 50°.

Altitude.	Refraction.	Altitude.	Refraction.
10°	5′ 19″	20	2′ 38″
11	4 51	25	2 04
12	4 27	30	1 41
13	4 07	35	1 23
14	3 49	40	1 09
15	3 34	45	58
16	3 20	50	49
17	3 08	60	34
18	2 57	70	21
19	2 48	80	10

Preparation of the Declination Settings for a Day's Work. The solar ephemeris gives the declination of the sun for the given day, for Greenwich mean noon. Since all points in America are west of Greenwich, by 4, 5, 6, 7, or 8 hours, the declination found in the ephemeris is the declination at the given place at 8, 7, 6, 5, or 4 o'clock A. M. of the same date, according as the place lies in the "Colonial," "Eastern," "Central," "Mountain," or "Pacific" time belts respectively.

The columns headed "Refraction Corrections" (see table) give the correction to be made to the declination, for refraction for any point whose latitude is 40°. If the latitude is more or less than 40°, these corrections are to be multiplied by the corresponding coefficient given in the table of "Latitude Coefficients" (page 148). Thus the refraction corrections in latitude 30° are 65 one-hundredths, and those of 50° 142 one-hundredths of the corresponding ones in latitude 40°. There is a slight error in the use of these latitude coefficients, but the maximum error will not amount to over 15 seconds, except when the sun is very near the horizon, and then any refraction becomes very uncertain. All refraction tables are made out for the mean (or average) refraction whereas the actual refraction at any particular time and place may be not more than one-half or as much as twice the mean refraction, with small altitudes. The errors made in the use of these latitude coefficients are therefore very small compared with the errors resulting from the use of the mean, rather than unknown actual, refraction which affects any given observation.

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*This table, as well as those following, is taken from the catalogue of George N. Saegmuller, Washington, D. C.

Latitude Coefficients.

LAT.	COEFF.	LAT.	COEFF.	LAT.	COEFF.	LAT.	COEFF.
15°	.30	27°	.56	39°	.96	51°	1.47
16	.32	28	.59	40	1.00	52	1.53
17	.34	29	.62	41	1.04	53	1.58
18	.36	30	.65	42	1.08	54	1.64
19	.38	31	.68	43	1.12	55	1.70
20	.40	32	.71	44	1.16	56	1.76
21	.42	33	.75	45	1.20	57	1.82
22	.44	34	.78	46	1.24	58	1.88
23	.46	35	.82	47	1.29	59	1.94
24	.48	36	.85	48	1.33	60	2.00
25	.50	37	.89	49	1.38		
26	.53	38	.92	50	1.42		

If the date of observation be between June 20 and September 20, the declination is positive and the hourly change negative; while if it be between December 20 and March 20, the declination is negative and the hourly change positive. The refraction correction is always positive; that is, it always increases numerically the north declination, and diminishes numerically the south declination. The hourly refraction corrections given in the ephemeris are exact each for the middle day of the five-day period, corresponding to that of hourly corrections. For the extreme days of any such period, an interpolation can be made between the adjacent hourly corrections, if desired.

By using standard time instead of local time, a slight error is made, but the maximum value of this error is found at those points when the standard time differs from the local time by one-half hour, and in the spring and fall when the declination is changing rapidly. The greatest error then, is less than 30 seconds, and this is smaller than can be set off on the vertical circle or declination arc. Even this error can be avoided by using the true difference of time from Greenwich in place of standard meridian time.

EXAMPLES FOR PRACTICE.

(1) Let it be required to prepare a table of declination for June 10, 1904, for a point whose latitude is 40° 20′, and which lies in the "Central Time" belt.

Since the time is 6 hours earlier than that at Greenwich, the declination given in the ephemeris is the declination at the given place at 6 A. M. of the same date. This is found to be 23° 0′ 18″. To this must be added the hourly change which is also plus and equal to 11.67″. The latitude coefficient is 1.013. The following table may now be made out.

HOUR	DECLINATION	REF. COR	SETTING	HOUR	DECLINATION	REF. COR	SETTING
7	+ 23° 0′ 30″	+ 1′ 10″	23° 1′ 40″	1	23° 1′ 41″	18″	23° 1′ 59″
8	+ 23° 0′ 41″	+ 44″	23° 1′ 25″	2	23° 1′ 52″	22″	23° 2′ 14″
9	+ 23° 0′ 53″	+ 29″	23° 1′ 22″	8	23° 2′ 04″	29″	23° 2′ 33″
10	+ 23° 1′ 5″	+ 22″	22° 1′ 27″	4	23° 2′ 16″	44″	23° 3′ 0″
11	+ 23° 1′ 17″	+ 18″	23° 1′ 35″	5	23° 2′ 28″	1′ 10″	23° 3′ 38″

PROBLEMS INVOLVING USE OF TRANSIT.

Perpendiculars and Parallels. *To erect a perpendicular to a line at a given point of the line.* Set up the transit over the given point, and with the verniers set to 0°, direct the line of sight along the given line. Clamp the lower motion, unclamp the upper motion, and turn off an angle of 90° in the proper direction for the required line.

To erect a perpendicular to an inaccessible line at a given point of the line. Let AB, Fig. 101, be the given inaccessible line, and A the point of the line at which it is proposed to erect the perpendicular AD. Select some point H from which can be distinctly seen the points A and B of the inaccessible line. Set up the transit at the point H, and measure the angle AHB. Also from the point H run out and measure a line of any convenient length, and in such a direction that the points A and B can be seen from its extremity, as E. Now measure the angles AHE and BHE. Now set up the transit at E, and measure the angles BEH, BEA, and AEH. In the triangle AHE, we know from measurement the length of the side HE, as also the angles AHE and AEH, from which may be calculated the length of the side AH, which is also one side of the triangle AHB. From the triangle BEH, we have the length HE, known by measure

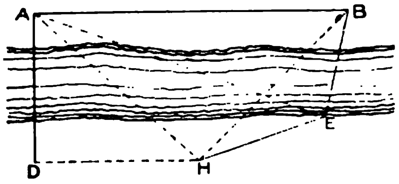


Fig. 101.

Refraction Correction.

Latitude, 40°.

January.	′ ″
1 2 3	1h. 1 58 2 2 16 3 3 04 4 6 23
4 5 6 7 8	1 1 54 2 2 11 3 2 59 4 6 01
9 10 11 12 13	1 1 51 2 2 07 3 2 51 4 5 40
14 15 16 17 18	1 1 46 2 2 01 3 2 40 4 5 00
19 20 21 22 23	1 1 42 2 1 56 3 2 31 4 4 35
24 25 26 27 28	1 1 37 2 1 58 3 2 22 4 4 07
29 30 31	1 1 32 2 1 44 3 2 13 4h. 3 41

February.	′ ″
1 2	
3 4 5 6 7	1h. 1 26 2 1 37 3 2 04 4 3 21
8 9 10 11 12	1 1 21 2 1 31 3 1 56 4 3 04
13 14 15 16 17	1 1 16 2 1 25 3 1 48 4 2 47 5 8 39
18 19 20 21 22	1 1 12 1 1 20 3 1 40 4 2 31 5 6 49
23 24 25 26 27	1 1 07 2 1 15 3 1 33 4 2 18 5h. 5 28
28	

March.	′ ″
1 2 3 4	1h. 1 03 2 1 10 3 1 27 4 2 06 5 4 39
5 6 7 8 9	1 0 59 2 1 06 3 1 21 4 1 56 5 4 04
10 11 12 13 14	1 0 55 2 1 02 3 1 15 4 1 47 5 3 34
15 16 17 18 19	1 0 52 2 0 58 3 1 10 4 1 39 5 3 08
20 21 22 23 24	1 0 48 2 0 54 3 1 05 4 1 32 5 2 51
25 26 27 28 29	1 0 45 2 0 50 3 1 01 4 1 25 5 2 34
30 31	1 0 42 2h. 0 47

April.	′ ″
1 2 3	3h. 0 57 4 1 19 5 2 18
4 5 6 7 8	1 0 39 2 0 44 3 0 54 4 1 14 5 2 08
9 10 11 12 13	1 0 36 2 0 41 3 0 51 4 1 10 5 1 58
14 15 16 17 18	1 0 34 2 0 38 3 0 48 4 1 06 5 1 49
19 20 21 22 23	1 0 32 2 0 36 3 0 45 4 1 02 5 1 42
24 25 26 27 28	1 0 30 2 0 34 3 0 42 4 0 58 5 1 36
29 30	1 0 28 2h. 0 32

May.	′ ″
1 2 3	1h. 0 28 2 0 32 3 0 39 4 0 55 5 1 30
4 5 6 7 8	1 0 26 2 0 30 3 0 37 4 0 53 5 1 26
9 10 11 12 13	1 0 25 2 0 29 3 0 36 4 0 51 5 1 22
14 15 16 17 18	1 0 23 2 0 27 3 0 34 4 0 49 5 1 18
19 20 21 22 23	1 0 22 2 0 26 3 0 33 4 0 47 5 1 15
24 25 26 27 28	1 0 21 2 0 25 3 0 32 4 0 46 5 1 13
29 30 31	1 0 20 2 0 24 4 0 31 4 0 44 5h. 1 11

June.	′ ″
1 2	5h. 1 11
3 4 5 6 7	1 0 19 2 0 23 3 0 30 4 0 43 5 1 10
8 9 10 11 12	1 0 18 2 0 22 3 0 29 4 0 43 5 1 09
13 14 15 16 17	1 0 18 2 0 22 3 0 29 4 0 42 5 1 08
18 19 20 21 22	1 0 18 2 0 22 3 0 28 4 0 42 5 1 08
23 24 25 26 27	1 0 18 2 0 22 3 0 29 4 0 42 5 1 08
28 29 30	1 0 18 2 0 22 3 0 29 4h. 0 43

July.	′ ″
1 2	5h. 1 09
3 4 5 6 7	1 0 19 2 0 23 3 0 30 4 0 43 5 1 10
8 9 10 11 12	1 0 20 2 0 24 3 0 31 4 0 44 5 1 11
13 14 15 16 17	1 0 21 2 0 25 3 0 32 4 0 46 5 1 13
18 19 20 21 22	1 0 22 2 0 26 3 0 33 4 0 47 5 1 15
23 24 25 26 27	1 0 23 2 0 27 3 0 34 4 0 49 5 1 18
28 29 30 31	1 0 25 2 0 29 3 0 36 4 0 51 5h. 1 22

August.	′ ″
1	
2 3 4 5 6	1h. 0 26 2 0 30 3 0 37 4 0 53 5 1 26
7 8 9 10 11	1 0 28 2 0 32 3 0 39 4 0 55 5 1 30
12 13 14 15 16	1 0 30 2 0 34 3 0 42 4 0 58 5 1 36
17 18 19 20 21	1 0 32 2 0 36 3 0 45 4 1 02 5 1 42
22 23 24 25 26	1 0 34 2 0 38 3 0 48 4 1 06 5 1 49
27 28 29 30 31	1 0 36 2 0 41 3 0 51 4 1 10 5h. 1 58

September.	′ ″
1 2 3 4 5	1h. 0 39 2 0 41 3 0 54 4 1 14 5 2 08
6 7 8 9 10	1 0 42 2 0 47 3 0 57 4 1 19 5 2 18
11 12 13 14 15	1 0 45 2 0 50 3 1 01 4 1 25 5 2 34
16 17 18 19 20	1 0 48 2 0 54 3 1 05 4 1 32 5 2 51
21 22 23 24 25	1 0 52 2 0 58 3 1 10 4 1 39 5 3 08
26 27 28 29 30	1 0 55 2 1 02 3 1 15 4 1 47 5h. 3 34

October.	′ ″
1 2 3 4 5	1h. 0 59 2 1 06 3 1 21 4 1 56 5 4 04
6 7 8 9 10	1 1 03 2 1 10 3 1 27 4 2 06 5 4 39
11 12 13 14 15	1 1 07 2 1 15 3 1 33 4 2 18 5 5 39
16 17 18 19 20	1 1 12 2 1 20 3 1 40 4 2 31 5 6 29
21 22 23 24 25	1 1 16 2 1 25 3 1 48 4 2 47 5 8 39
26 27 28 29 30	1 1 21 2 1 31 3 1 56 4 3 04 5 11 01
31	1h. 1 26 1 37 2 04

November.	′ ″
1 2 3 4	2h. 3 21 3 13 57 4 5
5 6 7 8 9	1 1 32 2 1 44 3 2 13 4 3 41 5
10 11 12 13 14	1 1 37 2 1 50 3 2 22 4 4 07 5
15 16 17 18 19	1 1 42 2 1 56 3 2 31 4 4 35 5
20 21 22 23 24	1 1 46 2 2 01 3 2 40 4 4 59 5
25 26 27 28 29	1 1 50 2 2 06 3 2 49 4 5 33 5h.
30	

December.	′ ″
1 2 3 4	1h. 1 54 2 2 11 3 2 59 4 6 01 5
5 6 7 8 9	1 1 58 2 2 16 3 3 04 4 6 23 5
10 11 12 13 14	1 2 00 2 2 19 3 3 09 4 6 38 5
15 16 17 18 19	1 2 01 2 2 20 3 3 11 4 6 47 5
20 21 22 23 24	1 2 01 2 2 20 3 3 11 4 6 49 5
25 26 27 28 29	1 2 00 2 2 19 3 3 09 4 6 43 5h.
30 31	

ment, as well as the angles BHE and BEH, from which we can calculate the length of the side BH, which is also one side of the triangle AHB. Therefore in the triangle AHB, we have the lengths of the two sides AH and BH by calculation; and the angle AHB by measurement. We can therefore calculate the angle HAB, which equals the angle AHD. Set up the transit at H, sight to A, and turn off the angle AHD (= HAB), measuring off HD of a length equal to AH cos AHD. Then AD will be the perpendicular required, and its length will equal AH sin AHD.

The calculation is as follows: In the triangle AHE, the angle HAE = 180° − (AHE + AEH), and therefore AH : HE : : sin AEH : sin HAE; or, $AH = HE\frac{\sin AEH}{\sin HAE}$.

In the triangle HEB, HBE = 180° − (BHE + BEH), and therefore HB : HE : : sin HEB : sin HBE;

or $HB = HE\frac{\sin HEB}{\sin HBE}$.

In the triangle AHB, the sum of the angles HAB and HBA = 180° − AHB. Let x represent the difference of the angles HAB and HBA. Then, from trigonometry,

AH + HB : AH − HB :: tan ½ (HAB + HBA) : tan ½ (HAB − HBA);

or, AH + HB : AH − HB :: tan ½ (180° − AHB) : tan ½ x;

or, AH + HB : AH − HB :: cot $\frac{AHB}{2}$: tan ½ x.

From this last proportion we find x, the difference of the two angles HAB and HBA. We then have the simultaneous equations:

$$HAB + HBA = c \text{ (say)}$$
$$HAB - HBA = d \text{ (say)}$$

Therefore $HAB = \frac{c+d}{2}$; and $HBA = \frac{c-d}{2}$.

EXAMPLE FOR PRACTICE

Given HE (Fig. 101) = 125 feet; AHE = 122°; AHB = 94°; BHE=28°; BEH = 121°; BEA = 80°; AEH=41°. It is required to find the angle AHD, the length of HD, and the length of AD

Ans. AHD = 50° 54'; HD = 176.92 feet; AD = 217.92 feet

To let fall a perpendicular to a line from a given point. Let AB, Fig, 102, be the given line, and C the point. Set up the transit at some point A of the given line, and measure the angle BAC. Take the instrument to C, sight to A and turn off an angle ACB = 90° - BAC. The instrument will then sight in the direction of the required perpendicular CB.

To let fall a perpendicular to a line from an inaccessible point. Let BC, Fig. 103, be the given line and A the inaccessible point from which it is desired to let fall the perpendicular upon BC. Set up the instrument, as at B; and, after measuring the length of BC, measure the angle ABC. Take the instrument to C, and measure the angle ACB. Then in the triangle ABC,

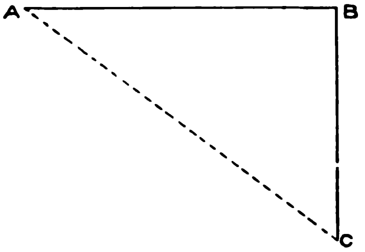


Fig. 102.

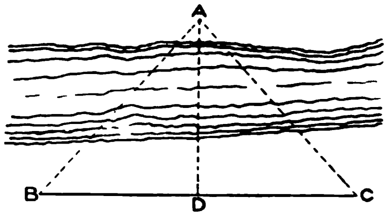


Fig. 103.

$$AB : BC : : \sin ACB : \sin (ACB + ABC);$$

or,
$$AB = BC \cdot \frac{\sin ACB}{\sin (ACB + ABC)};$$

$$BD = AB \cos ABC;$$

and,
$$BD = BC \frac{\tan ACB}{\tan ACB + \tan ABC}.$$

EXAMPLE FOR PRACTICE.

Given BC (Fig. 103) = 250 feet; ABC = 63°15′; ACB = 55°40′. Calculate the length of BD, and the length of AD.

Ans. $\begin{cases} BD = 126.2 \text{ feet.} \\ AD = 250.7 \text{ feet.} \end{cases}$

To let fall a perpendicular to an inaccessible line from a given point outside of the line. Let AB, Fig. 104, be the inaccessible line, and C the point from which it is desired to let fall the perpendicular to AB. Through C run out and measure a line of any convenient length, as CD, and measure the angles ACB

DCB, and DCA. Set up the instrument at D, and measure the angles ADC and BDC. In the triangle BDC, we have given two angles and the included side, from which can be calculated the length of the side CB, In the triangle ADC, we have given two angles and the included side, from which can be calculated the length of the side AC. Then, in the triangle ACB, we have the lengths of the sides AC and CB, and the included angle ACB, from which can be calculated the angle CAB. If, then, the instrument be set up at C, and an angle ACE be turned off equal to 90° – BAC, the line of sight will point in the direction of the required perpendicular, and the length of the perpendicular will be given by AC cos ACE.

This same method will serve *to trace a line through a given point parallel to an inaccessible line.* For if, with the instrument at C, an angle ACA′ be turned off equal to CAB, the line A′ B′ will be parallel to AB.

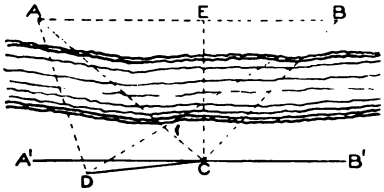


Fig. 104.

Obstacles to Alignment. *By Perpendiculars:* When a tree, house, or other obstacle obstructing the line of sight (see Fig. 105) is encountered, set up the transit at the point B, turn off a right angle, and measure the length of the line BC. Erect a second perpendicular CD at C, and measure its length. At D erect a third perpendicular DE, making DE = BC. Then the fourth perpendicular EF will be in the direction of the required line. The distance from B to E will be given by CD. If perpendiculars cannot be conveniently set off, let BC and DE make any equal angle with the line AB, so that CD will be parallel to it.

By an Equilateral Triangle. At B turn off from the direction of AB produced, an angle of 60° in the direction of BC (see Fig. 106), and make BC any convenient length sufficient to clear the obstacle. Set up the instrument at C and turn off an angle of 60° from BC to CD and make CD of a length equal to BC Finally at D turn off a third angle of 60° from CD to DB, and the line DE will be in the direction of AB produced. The distance BD will equal BC or CD.

By Triangulation. Let AB, Fig. 107, be the line to be prolonged beyond the obstacle. Choose some point as C from which can be seen the line AB as well as some point D beyond the obstacle. With the transit at A, measure the length of AB and measure the angle BAC. Set up the transit at C, and measure the angles BCA and ACD. Then, in the triangle ACB, we have one side and two angles known, from which can be calculated the lengths of AC and BC. In the triangle ACD, we know the length AC and the angles BAC and ACD, from which can be calculated the length CE, the angle BEC, and the distance AE. Therefore from C measure the distance CE, set up the transit at E, and turn off the angle CEF equal to 180° minus the angle BEC, for the direction of the required line. The length of BE will evidently equal AE – AB.

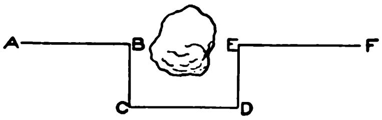


Fig. 105.

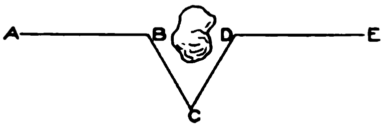


Fig. 106.

By a Random Line. When a wood, hill, or other obstacle prevents one end of a line (as B, Fig. 108) being seen from the other end A, run out and measure a random line, as AC, as nearly in the required direction as may be guessed, until a point C is reached from which B can be seen. Now, if convenient, measure the perpendicular offset from AC to the point B, from which can be calculated the angle CAB. Tan. $CAB = \frac{BC}{AC}$. If a right angle cannot be turned off at C, turn off any convenient angle and measure the distance CB; then, in the triangle ACB, there are given two sides and the included angle, from which can be calculated the angle CAB. Now taking the transit back to A, the angle CAB can be turned off in the proper direction from

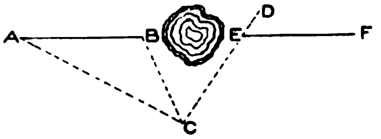


Fig. 107.

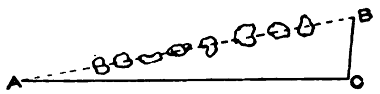


Fig. 108.

AC, and the correct line AB can be run out and measured in the proper direction.

By Latitudes and Departures. When a single line such as AC cannot be run so as to come opposite the given point B (Fig. 109), a series of zigzag lines (as AC, CD, DE, EF, and FB) can be run in any convenient direction, so as at last to arrive at the desired point B. Any one of these lines (as, for instance, AC) may be taken as a meridian to which all of the others may be referred, and their bearings therefrom deduced. Calculate the total latitudes and departures of these lines, as AX and BX; then the bearing of the required line BA with respect to AC will be given by Tan. BAC $= \frac{BX}{AX}$.

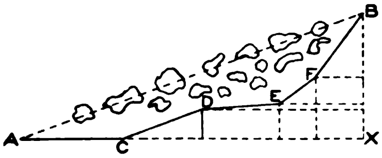


Fig. 109.

By Triangulation. When obstacles prevent the use of either of the preceding methods, if a point C can be found from which A and B are accessible (see Fig. 110), measure the distances CA and CB, and the angle ACB, from which can be calculated the length of the side AC and the angle CAB. Now measure the angle ACD to some point D beyond the obstacle; then, in the triangle ACD, we have two angles and the included side, from which may be calculated the length of the side CD. Measure the distance CD in the proper direction, set up the transit at D, and turn off an angle CDB equal to the supplement of ADC, for the direction of the required line.

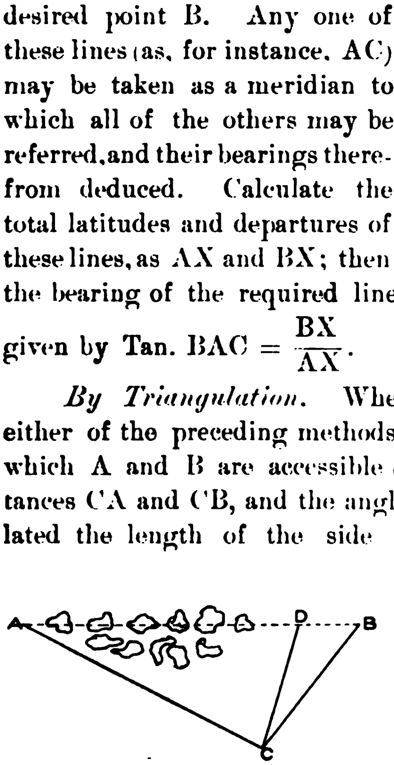


Fig. 110.

The distance from A to D may also be calculated from the triangle ACD, the stake at D given its proper number, and the line continued. If the distances CA and CB cannot be measured, it will be necessary to measure a base-line through C, from the extremities of which the angles to A and B can be measured and the required distances calculated as before.

The following problem, as illustrated in Fig. 111, is of frequent occurrence in line surveys. The line AB of the survey having been brought up to one side of a stream, it is desired to continue the line of the survey across the stream to the point C, the latter point being visible from B and accessible. It is required to find the length of the line BC, that the stake at C may be given its proper number, and the survey continued from that point. With the transit at B, turn off the required angle to locate the point C, and drive a stake at that point. If possible, deflect from BC a right angle to some point E, and measure the length of BE. Take the transit to E, and measure the angle BEC. The distance BC is therefore:

$$BC = BE \tan BEC.$$

If it is not possible to turn off a right angle at B, then through B run a line (as BE′) in any convenient direction, and measure its length; measure also the angles E′BC and BE′C. In the triangle CBE′, there are then given two angles and the included side, from which the side BC can be calculated. Should it be necessary to take soundings at certain intervals (as, say, 50 or 100 feet across the stream), then in the triangle BE X there are given the distance BX, the distance E′X, and the angle XBE′, from which can be calculated the angle BE′X. With the transit at E′, turn off from BE′ the angle BE′X. Now, starting a boat from the shore, direct it in line from B to C until it comes upon the line of sight of the transit from E′ to X. At that point take soundings, and similarly for the point X′, etc. If the point C is not visible from B, find some point, as E (see Fig. 112), from which B and C are visible, and measure the angle BEC and the distance EB. Find a second point, as F, from which E and C are visible, and measure the angles CEF and EFC and the distance EF. Then, in the triangle ECF, there are given two angles and the included side, from which can be calculated the distance EC. In the triangle BCE, then, there are given two sides and the included

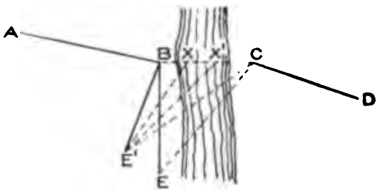


Fig. 111.

angle, and from these the third side BC and the angle EBC can be found. The stake C can now be numbered, and the bearing of BC deduced.

EXAMPLES FOR PRACTICE.

1. In Fig. 111, given BE′ = 210 feet; angle CBE′ = 110° 15′; angle BE′C = 34°20′; stake B numbered 8 + 54. It is required to find the number of the stake C.

2. (*a*) In Fig. 112, given EF = 250 feet; BE = 128 feet; angle EFC = 46° 40′; angle CEF = 103° 30′; angle BEC = 39° 10′. If the stake at B is numbered 12 + 20, it is required to find the number of the stake at C.

(*b*) If the bearing of the line AB is S 75°E, and the deflection angle of BE from AB is 104° to the *right*, find the bearing of BC.

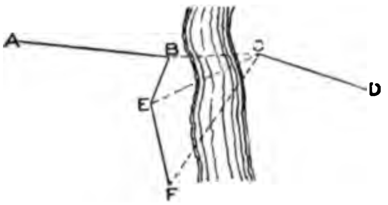


Fig. 112.

To Supply Omissions. Any two omissions in a closed survey—whether of the direction or of the length, or of both, of one or more lines of the survey—can always be supplied by the application of the principle of latitude and departures, although this method should be resorted to only in cases of absolute necessity, since any omission renders the checking of the field work impossible. In the following paragraphs, the methods outlined will apply equally whether the survey has been made with the transit or with the compass.

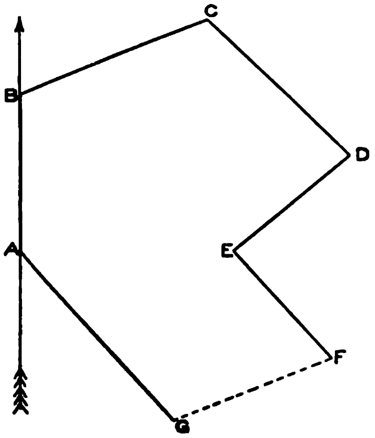


Fig. 113.

CASE 1. *When the length and bearing of any one side are wanting.* In Fig. 113, let the dotted line FG represent the course whose length and bearing are wanting. Calculate the latitudes and departures of the remaining courses; and since in a closed survey the algebraic sum of the latitudes and departures should equal zero, therefore the difference of the latitudes will be the latitude of the missing line, and the difference of the longitudes will be the required longitude. The latitude and longitude of the line, form the sides of a right triangle, from which we have:

$$\text{Tangent of Bearing} = \frac{\text{Longitude}}{\text{Latitude}}.$$

The required length will be given by $L = \dfrac{\text{Latitude}}{\text{Cos Bearing}}$.

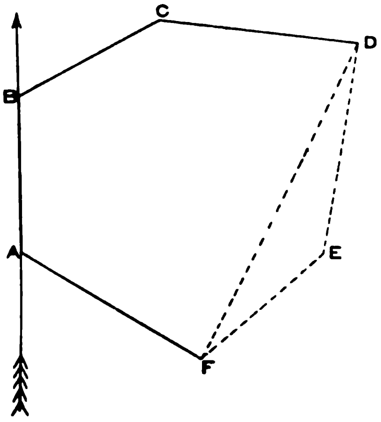


Fig. 114.

CASE 2. *When the length of one side and the bearing of another are wanting.*

(*a*) WHEN THE DEFICIENT SIDES ADJOIN EACH OTHER. In Fig. 114, let the bearing of DE, and the length of FE, be lacking. Draw DF. From the preceding proposition we can calculate the bearing and length of DF, as though DE and EF did not exist. Then, in the triangle DEF, we have given the lengths DF and DE and the angle DEF, from which can be calculated the angle FDE and the length EF.

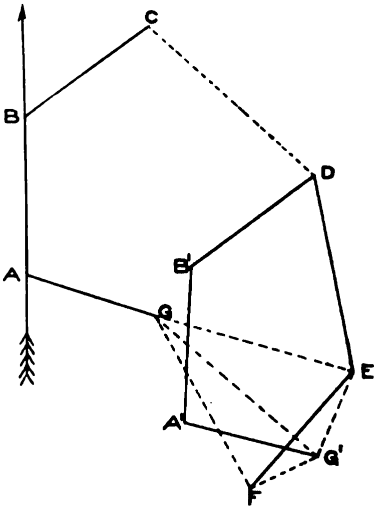


Fig. 115.

(*b*) WHEN THE DEFICIENT SIDES ARE SEPARATED FROM EACH OTHER. In Fig. 115 let ABCDEFGA represent a seven-sided field, in which the length of CD, and the bearing of FG, are wanting. Draw DB′, B′A′, A′G′, of the same lengths, and parallel respectively to CB, BA, and AG. Connect G′ with GE and F. Then, in the figure DB′A′G′E, there are given the lengths and bearings of all of the courses but G′E. The length and bearing of the last course can be calculated by the principles of Case 1. Then, in the triangle EFG′, there are given the lengths and bearings of EF and EG′, from which can be calculated the length and bearing of FG′. Therefore, in the triangle GFG′, since GG′ is equal in length and parallel to CD, there are given the *lengths* of GF and FG′, and the *bearings* of GG′ and FG′, from which can be calculated the length of GG′ and the bearing of GF.

CASE 3. *When the lengths of two sides are wanting.*

(*a*) WHEN THE DEFICIENT SIDES ADJOIN EACH OTHER. In the seven-sided Fig. 116, let the lengths of DE and EF be wanting. Calculate the length and bearing of DF by the principles of Case 1. Then, in the triangle EDF, there are given the angles at D and F, and the length of DF, from which can be calculated the lengths of DE and EF.

(*b*) WHEN THE DEFICIENT SIDES ARE SEPARATED FROM EACH OTHER. In Fig. 115, let the lengths of CD and GF be wanting. As before, having calculated the length and bearing of FG′, in the triangle FGG′, the angle at G can be calculated from the bearings of FG and GG′; the angle at G′ from the bearings of GG′ and FG′; and the angle at F from the bearings of FG and FG′. There are given then the three angles of the triangle, and the length of one side, from which can be calculated the lengths of the other sides.

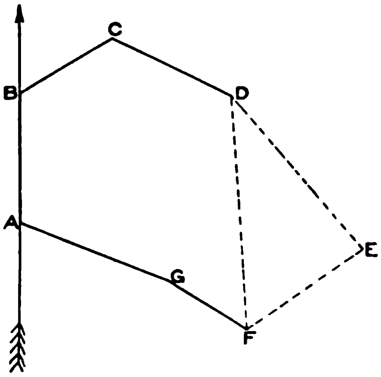


Fig. 116.

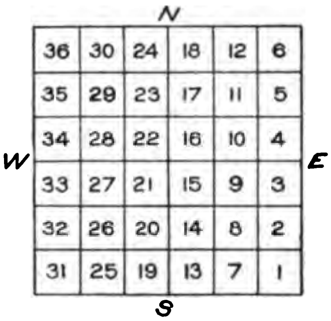
CASE 4. *When the bearings of two sides are wanting.*

(*a*) WHEN THE DEFICIENT SIDES ADJOIN EACH OTHER. In Fig. 116, find the length and bearing of DF as before. Then, in the triangle DEF, there are given the lengths of the three sides, from which can be calculated the required angles.

(*b*) WHEN THE DEFICIENT SIDES ARE SEPARATED FROM EACH OTHER. In Fig. 115, let the bearings of CD and GF be wanting. Calculate the length and bearing of FG′ as before. Then, in the triangle FGG′, there are three sides known, from which can be calculated the three angles, and therefore the bearings can be deduced.

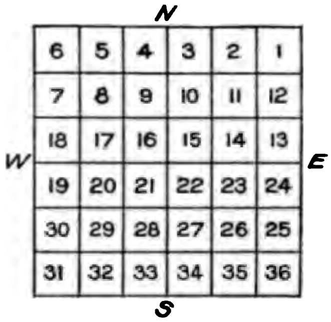
UNITED STATES PUBLIC LAND SURVEYS.

The first surveys of the public lands of the United States were carried out in Ohio, under an act of Congress approved May 20th, 1785. This act provided for townships 6 miles square, containing 36 sections of 1 mile square. The townships 6 miles square, were laid out in ranges, extending northward from the Ohio River, the townships being numbered from south to north, and the ranges from east to west. The territory embraced in these early surveys forms a part of the present state of Ohio and is known as "The Seven Ranges." The sections were numbered from 1 to 36 commencing with No. 1 in the *southeast* corner of the township, and running from *south* to *north* in each tier, to No. 36 in the *northwest* corner of the townships as shown in Fig. 117.



36	30	24	18	12	6
35	29	23	17	11	5
34	28	22	16	10	4
33	27	21	15	9	3
32	26	20	14	8	2
31	25	19	13	7	1

Fig. 117.



6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Fig. 118.

A subsequent act of Congress, approved May 18th, 1796, provided for the appointment of a surveyor general, and directed the survey of the lands northwest of the Ohio River, and above the mouth of the Kentucky River. This act provided that "the sections shall be numbered respectively, beginning with the number one in the northeast section, and proceeding west and east alternately, through the township, with progressive numbers till the thirty-sixth be completed." This method is shown in Fig. 118 and is still in use.

An act of Congress, approved Feb. 11th 1805, directs the subdivision of the public lands into quarter sections, and provides that all the corners marked in the public surveys shall be established as the proper corners of sections, or subdivisions of sections, which they were intended to designate, and that corners of half and quarter sections *not marked* shall be placed, as nearly as possible, "equidistant from those two corners which stand on the same line." This act further provides that "the boundary lines actually run and marked * * * shall be established as the proper boundary lines of the sections or subdivisions for which they were intended; and the length of such lines as returned by * * * the surveyors * * * shall be held and considered as the true length thereof"......

An act of Congress, approved April 24th, 1820, provides for the sale of public lands in half-quarter sections, and requires that "in every case of the division of a quarter section the line for the division thereof shall run north and south. An act of Congress, approved April 5th, 1832, directed the subdivision of the public lands into quarter-quarter-sections and that in every case of the division of a half-quarter section, the dividing line should run east and west; and that fractional sections should be subdivided under rules and regulations prescribed by the Secretary of the Treasury.

By an act of Congress, approved March 3rd, 1849, the Department of the Interior was created, and the act provided "That the Secretary of the Interior shall perform all the duties in relation to the General Land Office, of supervision and appeal now discharged by the Secretary of the Treasury. * * *" By this act the General Land Office was transferred to the Department of the Interior where it still remains.

The division of the public lands is effected by means of meridian lines and parallels of latitudes established six miles apart. The squares thus formed are called *Townships*, and contain 36 square miles, or 23,040 acres "as nearly as may be." All of the townships situated north or south of each other, form a *Range* and are named by their number east or west of the principal meridian. Thus, the first range west of the meridian would be designated as Range 1 West (R. 1. W.). Each *tier* of townships is named by its number north or south of the base line, as Township 2 North (T. 2. N.).

Existing laws further require that each township shall be divided into thirty-six sections, by two sets of parallel lines, one governed by true meridians and the other by parallels of latitude, the latter intersecting the former at right angles, at intervals of one mile; and each of these sections must contain, as nearly as possible, six hundred and forty acres. These requirements are evidently inconsistent because of the convergency of the meridians, and the discrepancies will be greater as the latitude increases.

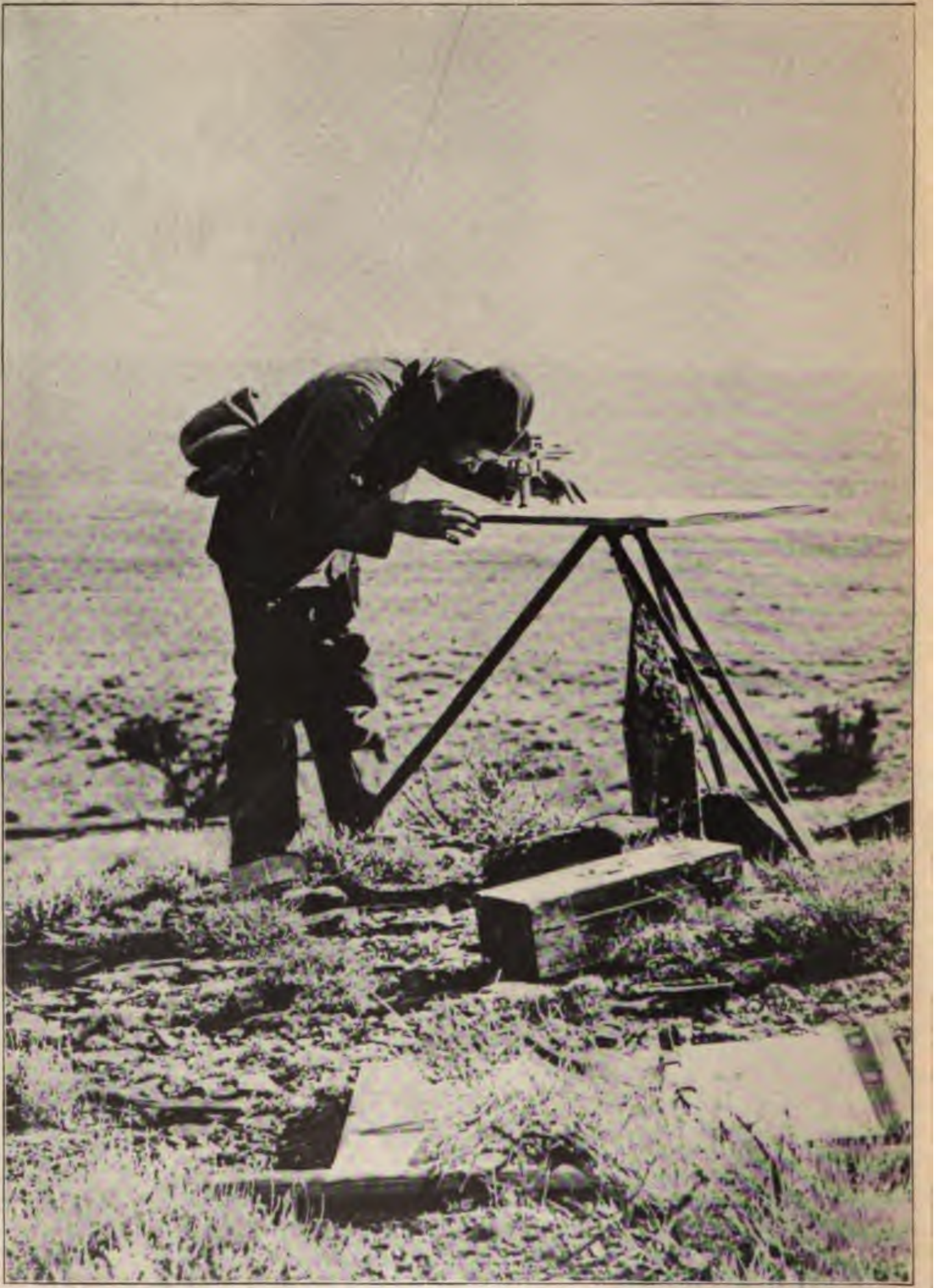
In view of these facts, it was provided in section 3 of the act of Congress approved May 10th, 1800, that "in all cases where the exterior lines of the townships, thus to be subdivided into sections and half-sections, shall exceed, or shall not extend six miles, the excess or deficiency shall be specially noted, and added to or deducted from the western or northern ranges of sections or half-sections in such township, according as the error may be in running lines from east to west, or from south to north; the sections and half-sections bounded on the northern and western lines of such townships shall be sold as containing only the quantity expressed in the returns and plots, respectively, and all others as containing the complete legal quantity."

To harmonize these various requirements as fully as possible, the following methods have been adopted by the general land office.

Initial points are first established astronomically under special instructions, and from this initial point a "principal meridian" is laid out north and south. Through this initial point a "base line" is laid out as a parallel of latitude running east and west. On the principal meridian and base lines, the half-mile, mile and six-mile corners are permanently located, and in addition, the meander corners at the intersection of the line with all streams, lakes or bayous prescribed to be meandered. These lines may be run with solar instruments, but their correctness should be checked by observations with the transit upon Polaris at elongation.

Standard parallels, also called correction lines, are run east and west from the principal meridian at intervals of twenty-four miles north and south of the base line, and the law provides that "where standard parallels have been placed at intervals of thirty or thirty-six miles, regardless of existing instructions, and where gross irregularities require additional standard lines, from which to

THE NEW YORK



TOPOGRAPHER OF U. S. GEOLOGICAL SURVEY AT WORK ON THE PLAINS OF COLORADO initiate new, or upon which to close old surveys, an intermediate correction line should be established to which a *local* name may be given: and the same will be run, in all respects, like the regular standard parallels."

Guide meridians are extended *north* from the base line. or standard parallels, at intervals of twenty-four miles east and west of the principal meridian.

When conditions are such as to require the guide meridians to run *south* from a standard parallel or a correction line, they are initiated at properly established closing corners of the given parallel. That is to say, they are begun from the point on the parallel at which they would have met it if they had been run *north* from the next southern parallel. This point is obtained from computation, and is less than twenty-four miles from the next eastern or western meridian by the convergence of the meridians in twenty-four miles.

In case guide meridians have been improperly located too far apart, auxiliary meridians may be run from standard corners. and these may be designated by a local name.

The angular convergence of two meridians is given by the equation

$$\phi = m \sin \mathrm{L} \qquad (1)$$

where m is the angular difference in longitude of the meridians, and L is the mean latitude of the north and south length under consideration.

The linear convergence in a given length l is

$$c = l \sin \phi \qquad (2)$$

The radius of a *parallel* at any latitude L is given by the equation

$$r = \cos \mathrm{L} \qquad (3)$$

where R is the mean radius of curvature of the earth.

The distance between meridians is usually given in miles and this must be reduced to degrees. To do this it is first necessary to find the linear value of one degree of longitude at the mean latitude from the proportion.

$$1^\circ : 360^\circ :: x : 2\pi r \qquad (4)$$

the value of r being found from (3)

Equation (4) will give results sufficiently accurate, although in strict accuracy R should be the radius of curvature at the mean latitude.

For full details of public-land surveying, see "Manual of Surveying Instructions for the Survey of the Public Lands of the United States," issued by the Commissioner of the General Land Office. These "Instructions" are prepared for the direction of those engaged on the public land surveys, and new editions are issued from time to time.

Much of the foregoing in very condensed form is taken from the edition of 1894.

The following table gives the convergency both in angular units and linear units for township 6 miles square, between latitudes 30° and 70° north.

Let it be required to find from the table the linear convergence for a township situated in latitude 38° 29′ north.

Looking in the table opposite 39° we find the linear convergence.

For 39° = 58.8 links
For 38° = 56.8 links
Difference for 1° = 2.0 links
Difference for 1′ = 2.0 ÷ 60 = .0333 links
Difference for 29′ = .0333 × 29 = .97 links

Therefore total convergence for latitude 38° 29′ = 56.8 + 0.97 links = 57.77 links.

BASE MEASUREMENT.

It is not intended in what follows to go into the details of the measurement of a base for an extended system of triangulation, as that properly belongs to Geodetic Surveying. Some description of base measuring apparatus will be given, with illustrations of various devices, and special attention will be given to the use of the tape in the accurate measurement of lines such as occur in usual field operations of Plane Surveying.

Lat.	Convergency.			Lat.	Convergency		
	On the Parallel.	Angle.			On the Parallel.	Angle.	
Degrees.	Links.	Minutes.	Seconds.	Degrees.	Links.	Minutes.	Seconds.
30	41.9	3	0	50	86.4	6	12
31	43.6	3	7	51	89.6	6	25
32	45.4	3	15	52	92.8	6	39
33	47.2	3	23	53	96.2	6	54
34	49.1	3	30	54	99.8	7	9
35	50.9	3	38	55	103.5	7	25
36	52.7	3	46	56	107.5	7	42
37	54.7	3	55	57	111.6	8	0
38	56.8	4	04	58	116.0	8	19
39	58.8	4	13	59	120.6	8	38
40	60.9	4	22	60	125.5	8	59
41	63.1	4	31	61	130.8	9	22
42	65.4	4	41	62	136.3	9	46
43	67.7	4	51	63	142.2	10	11
44	70.1	5	1	64	148.6	10	38
45	72.6	5	12	65	155.0	11	8
46	75.2	5	23	66	162.8	11	39
47	77.8	5	23	67	170.7	12	13
48	80.6	5	46	68	179.3	12	51
49	83.5	5	59	69	188.7	13	31
				70	199.1	14	15

Much of what follows is from the excellent treatise on Topographic Surveying by Herbert M. Wilson.

A trigonometric survey is usually carried over a country where the direct measurement of distances is impracticable, and since the calculations of these distances proceeds from the *direct* measurement of the base-line, this base line should be so located as to permit of its length being determined with any degree of accuracy consistent with the nature of the work involved.

To attain the desired results, the site should be reasonably level and afford room for a base of proper length so that its ends may be intervisible, and permit of the development of a scheme of primary triangulation giving the best-conditioned figures possible. Other things being equal, that site is best that includes solid ground: both for permanency of monuments and facility and accuracy of measurement.

Base Apparatus. In early days, base-lines were measured by means of wooden rods, varnished and tipped with metal. The rods were supported in trestles, the contacts between the ends being made with great care. Later, *compensated rods* were employed, as for instance the Contact-Slide Apparatus of the U. S. Coast Survey and the Repsold primary base bars of the U. S. Lake Survey, see Fig. 119, resulting in greater accuracy in the measurement of base lines. The use of the *iced bar* (see Fig. 120) by the U. S. Coast Survey, represents the highest development of base-measuring apparatus.

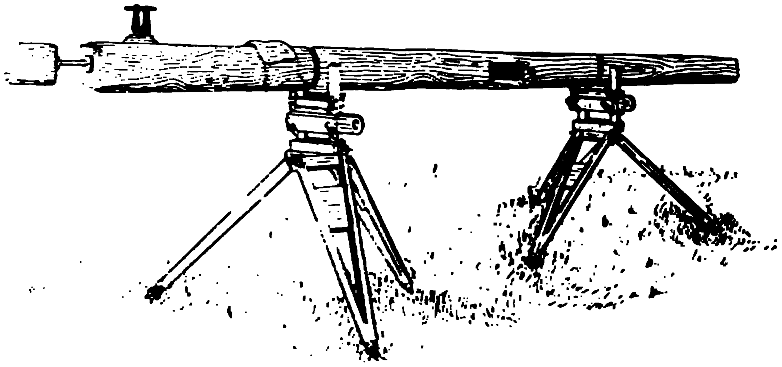


Fig. 119.

Within recent years the *steel tape* has become popular as the accuracy attainable with *its* use has become more fully appreciated.

Errors in Base Measurement. The following are the chief *sources of error* in base measurement:

1. Changes of temperature ;
2. Difficulties of making contact ;
3. Variations of the bars or tape from the standards.

The refinements of measurement consist especially in —

a. Standardizing the measuring apparatus, or its comparison with a standard of lengtn.

b. Determination of temperature, or its neutralization by the use of compensating bars.

c. Means adopted for reducing the number of contacts to the fewest possible, and of making these with the greatest degree of precision.

The *inherent difficulties* of measurement *with bars* of any kind are :

1. Necessity of measuring short bases because of the number of times which the bar must be moved.
2. Expense, as a considerable number of men are required.
3. Slowness, the measurement often occupying from a month to six weeks.

The *advantages* of measurement made with a *steel tape* are :

1. Great reduction in the number of contacts, as the tapes are about three hundred feet long as compared with bars of about twelve feet.
2. Comparatively small cost because of the few persons required.
3. Shortness of the time employed, an hour to a mile being an ordinary record in actual measurement
4. Errors in trigonometric expansion may be reduced by increasing the length of the base from 5 miles, the average length of a bar-measured base, to 8 miles, not an uncommon length for tape-measured bases.

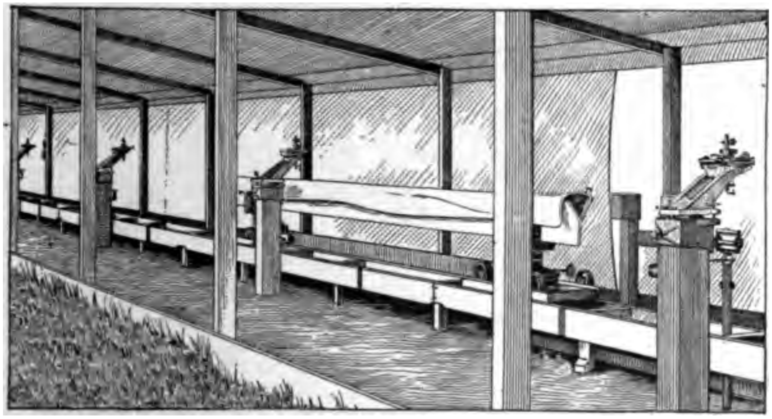


Fig. 120.

Steel tapes offer a means of measuring base lines which is superior to that obtained by measuring bars, because they combine the advantages of great length and simplicity of manipulation, with the precision of the shorter laboratory standards, providing only that means be perfected for eliminating the errors of temperature and of sag in the tape. Base lines can be so conveniently and rapidly measured with long steel tapes as to permit of their being made of greater length than has been the practice with lines measured by bars, and as a result, still greater errors may be introduced in tape-measured bases and yet not affect the ultimate expansion any more than will the errors in the latter, because of the greater length of the base.

The tapes used for this work are of steel, either 300 feet or 100 meters in length. The tapes used by the Coast Survey are 101.01 meters in length, 6.34 millimeters by 0.47 millimeters in cross-section, and weigh 22.3 grams per meter of length. They are subdivided into 20 meter spaces by graduations ruled on the surface of the tape, and their ends terminate in loops obtained either by turning back and annealing the tape on itself, or by fastening them into brass handles. When not in use, the tapes are rolled on reels for easy transportation.

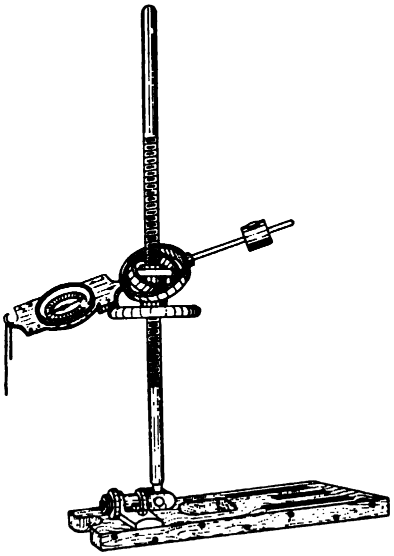
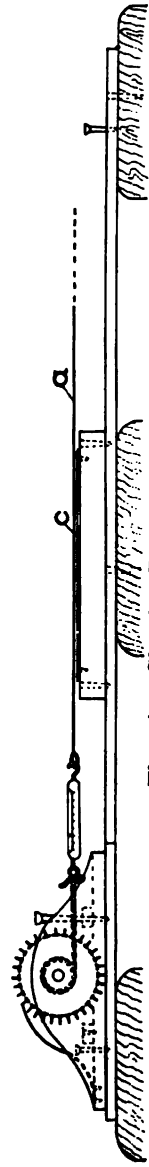


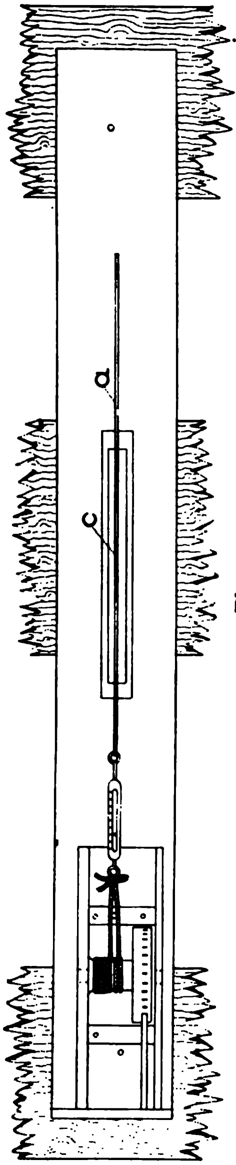
Fig. 121.

The steel tapes used by the Geological Survey are similar to those used by the Coast Survey, excepting in their length, which is a little over 300 feet. They are graduated for 300 feet and are subdivided every 10 feet, the last 5 feet of which at either end is subdivided to feet and tenths. The various instrument-makers now carry such tapes in stock, wound on hand-reels. All tapes must be standardized before and after use, by comparison with laboratory standards, and, if possible, thereafter frequently in the field by means of an iced-bar apparatus.

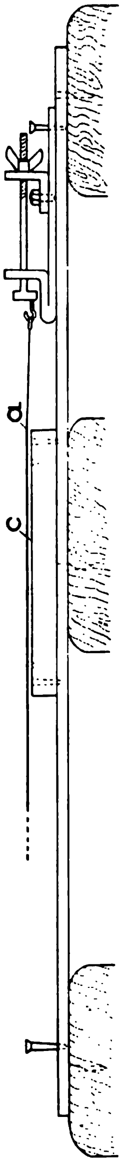
In measuring with steel tapes, a uniform tension must be applied. In order to get a uniform tension of 20 to 25 pounds, some form of stretcher should be used. That used by the U.S. Coast Survey consists of a base of brass or wood, 2 or 3 feet in length by a foot in width, upon which is an upright metallic standard, and to this is attached by a universal joint, an ordinary spring-balance, to which the handle of the tape is fastened. See Fig. 121. The upright standard is hinged at its junction with the base, so that when the tape is being stretched, the tapeman



Elevation, Showing Ratchet Wheel.



Plan.



Elevation, Showing Thumb Nut.

Fig. 122.

can put the proper tension on it by taking hold of the upper end of the upright standard and using it as a lever, and by pulling it back toward himself he is enabled to use a delicate leverage on the balance and attain the proper pull.

The *thermometers* used are ordinary glass thermometers, around the bubbles of which should be coiled thin annealed steel wire, so that by passing them in the air adjacent to the tape, a temperature corresponding to that of the tape can be obtained. Experience with such thermometers shows that they closely follow the temperature of the steel tape. For the best results, two thermometers should be used, each at about one-fourth of the distance from the extremities of the tape.

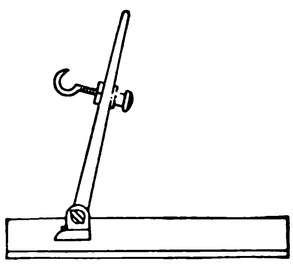


Fig. 123.

The stretching device used by the U. S. Geological Survey is much simpler and more quickly manipulated than that of the Coast Survey. The chief object to be attained in tension is steadiness and uniformity of tension; the simplest device which will attain this end is naturally the best. Two general forms of such devices are employed by the U. S. Geological Survey, one for the measurement of base lines along railways, where the surface of the ties or the roadbed furnishes support for the tape, and the device must therefore be of such kind as to permit of the ends being brought close to the surface; the other is employed in measurements made over rough ground, where the tape may frequently be raised to considerable heights above the surface and be supported upon pegs.

The stretcher used by the Geological Survey for measuring on railways is illustrated in Fig. 122, and was devised by Mr. H. L. Baldwin. It consists of an ordinary spring-balance attached to the forward end of the tape, where a tension of twenty pounds is applied, the rear end of the tape being caught over a hook which is held steadily by a long screw with a wing-nut, by which the zero of the tape may be exactly adjusted over the mark scratched on the zinc plate. The spring-balance is held by a wire running over a wheel, which latter is worked by a lever and held by ratchets in any desired position, so that by turning the wheel, a uniform strain is placed on the spring-balance, which is held at the desired tension by the ratchets.

The tape-stretcher used by the U. S. Geological Survey off railways consists of a board about 5 feet long, to the forward end of which is attached by a strong hinge, a wooden lever about 5 feet in length, through the larger portion of the length of which is a slot. See Fig. 123. Through the slot is a bolt with wing-nut, which can be raised or lowered to an elevation corresponding with the top of the hub over which measurement is being made; hung from the bolt is the spring-balance, to which the forward tapeman gives the proper tension by a direct pull on the lever, the weight of the lever and the friction in the hinge being such as to make it possible to bring about a uniform tension without difficulty. The zero on the rear end of the tape is adjusted over the contact mark on the zinc by means of a similar lever with hook-bolt and wing-nut, but without the use of spring-balance.

LAYING OUT THE BASE. The most laborious operation in base measurement is its preliminary preparation, which consists of:

1. Aligning with transit or theodolite;
2. Careful preliminary measurement for the placing of stakes on rough ground;
3. Placing of zinc marking-strips on the stakes.

Base lines measured with steel tapes across country are aligned with transit or theodolite, and are laid out by driving large hubs of 3 × 6 scantling into the ground, the tops of the same projecting to such a height as will permit a tape-length to swing free of obstructions. These large hubs are placed by careful preliminary measurement at exact tape-lengths apart, and between them as supports, long stakes are driven at least every 50 feet. Into the sides of these near their tops are driven horizontally, long nails, which are placed at the same level by eye, by sighting from one terminal hub to the next. The tape rests on these nails and on the surface of the terminal hubs are tacked strips of zinc on which to make the contact marks. A careful line of spirit-levels must be run over the base-lines, and the elevation of the hub or contact-mark of each tape-length must be determined in order to furnish data for reduction to the horizontal.

In measuring over rough ground, six men are necessary: two tape-stretchers, two markers, two observers of thermometers, one of whom will record. The co-operation of these men is obtained by a code of signals, the first of which calls for the application of the tension; then the two tape-stretchers by signal announce when the proper tension has been applied; then the rear observer adjusts the rear graduation over the determining mark on the zinc plate and gives a signal, upon hearing which, the thermometer-recorder near the middle of the tape lifts it a little and lets it fall on its supports, thus straightening the tape. Immediately thereafter the front observer marks the position of the tape graduation on the zinc plate, and at the same time the thermometers are read and recorded.

After the measurement of the base line has been completed in the field, the results of the measurement have to be reduced for various corrections, among which are:

Comparison with standard measure;
Corrections for inclination and sag of tape if such is used;
Correction for temperature.

The first correction to be applied is that of reducing the tape-line to the standard, "standardizing" the tape as it is called. By sending the tape to the National Bureau of Standards at Washington, D. C., a statement may be had of the length of the tape compared with the standard. For this service a small fee is charged. For an additional fee a statement may be had of the temperature and pull at the ends for which the tape is a standard.

As the length of a steel tape varies with the temperature, one of the most uncertain elements in the measurement of a base with the steel tape, is the change in the length of the standard due to changes of temperature. Corrections, therefore, must be made for every tape-length as derived from readings of one or more thermometers applied to the tape in the course of measurement.

Steel expands .0000063596 of its length for each degree Fahrenheit. This decimal multiplied by the average number of degrees of temperature above or below 62 degrees at the time of the measurement, gives the proportion by which the base is to be diminished or extended on account of temperature changes. This correction is applied usually by obtaining with great care, the mean of all thermometer readings taken at uniform intervals of distance during the measurement.

The data for the correction for inclination of base are obtained by a careful line of spirit-levels over the base-line. In the course of this leveling, elevations are obtained for every plug upon which the tape rests. The result of this leveling is to give a profile showing rise or fall in feet or fractions thereof between the points of change in inclination of the tape-line. From this and measured distances between these points, the angle of inclination is computed by the formula

$$\sin \theta = \frac{h}{D}$$

In which D is the length of the tape or measured base:
and h is the difference in height of the ends of tape or
measured base, expressed in feet.
θ is the angle of slope expressed in minutes.
The correction in feet to the distance is that computed by the equation

$$\text{Correction} = D \frac{\sin^2 1'}{2} \theta^2$$

An *approximate* formula for reducing distances measured upon sloping ground to the horizontal is expressed by the rule: Divide the square of the difference of level by twice the measured distance, subtract the quotient thus found from the measured distance, and the remainder equals the distance required; thus

$$d = D - \frac{h^2}{2D}$$

in which d equals the horizontal or reduced distance.

When the base measurement is made with steel tape across country, and accordingly is not supported in every part of its length, there will occur some change in its length, due to sag. As previously explained, the tape should be rested upon supports not less than 50 feet apart. With supports placed even this short distance apart, however, a change of length will occur between them, while even greater changes will occur should one or more supports be omitted as in crossing a road, ravine, etc. Since tapes are standardized by laying them upon a flat standard, it is necessary to determine the amount of shortening from the above causes.

The following reduction formulæ apply :

Let w = weight per unit of length of tape :
t = tension applied
$a = \frac{w}{t}$
n = number of sections into which tape is divided by supports.
l = length of any section
L = normal length of tape or right-line distance between n marks when under tension : $= nl$ approximately.

If a tape be divided by equidistant supports, the difference in distance between the end graduations, due to sag, or the correction for sag = dL becomes

$$dL = \frac{1}{24} a^2 (n_1 l_1^3 - n_2 l_2^3)$$

If one or more supports are omitted, then the omission of m consecutive supports shortens the tape by

$$\frac{1}{24} m (m + 1) (m + 2) a^2 l^3:$$

when l is the length of the section when no supports are omitted.

Example. Let $n = 6$; $l = 50$ feet ; $w = .0145$ = weight in pounds per foot found by dividing whole weight of tape by whole length ; $t = 20$ pounds.

$$d = \frac{nl}{24} \left(\frac{wl^2}{t}\right) = 0.0162 \text{ feet,}$$

which is the amount of shortening of each tape-length. This correction is always negative.

If there had been 86 full tape-lengths in measured base-line, the total corrections for sag would be 86 × .0162 = 1.393 feet.

THE PLANE-TABLE.

Construction. The plane-table consists essentially of a drawing-board mounted upon a tripod. This board is usually twenty-four by thirty inches, constructed in sections to prevent warping; it is attached to the tripod by a three-screw leveling base arranged to permit the board to be turned in azimuth and to be clamped in any position.

The instrument is designed to at once sketch in the field, to scale, the lengths and relative directions of all lines and the positions of objects to be included in the survey. For drawing straight lines, a steel ruler is provided upon which is mounted at each end, a pair of open sights like those of the compass, or, a telescope is mounted at the center of the ruler, fitted with stadia wires, a vertical arc and a longitudinal striding level. The eyepiece should be inverting, and whether the open sights or the telescope is used, the line of sight should always be parallel to the edge of the ruler. The straight edge with the attached telescope or open sights is called the *alidade*.

For leveling the instrument, two cylindrical levels, at right angles to each other, are mounted upon the alidade and either an attached or detached compass is provided for determining the bearing of lines.

For attaching the paper to the board, various devices are used. One consists of a roller at each end of the table upon one of which the paper is wound up as it is unrolled from the other, the edges of the paper being held close to the board by spring clips. This arrangement permits the paper to be used in a continuous roll and to be tightly stretched over the board. The use of the continuous roll of paper is undesirable, however, and separate sheets of proper size should be used, attached to the board and held firmly in place by the spring clips provided with the instrument. The use of thumb-tacks should be avoided.

Under the most favorable conditions, the plane-table is a very awkward instrument and difficult to handle, but it is admirably adapted to filling in the details of a topographical survey. For this purpose it is the standard instrument of the United States Geodetic Survey and is also largely used by the United States Geological Survey. It cannot be used on damp or very windy days and is not therefore, of as general utility as the transit and stadia.

Fig. 124 shows one form of construction of the plane table with leveling screws and Fig. 124*a* shows a plane table with a much simpler form of leveling head. This latter was designed by Mr. W. D. Johnson and has received the approval of the topographers of the United States Geological Survey. The whole arrangement is very light, but does not permit of as close leveling as does the usual form with leveling screws.

Adjustments.

1st. *To determine whether the edge of the ruler is straight.*

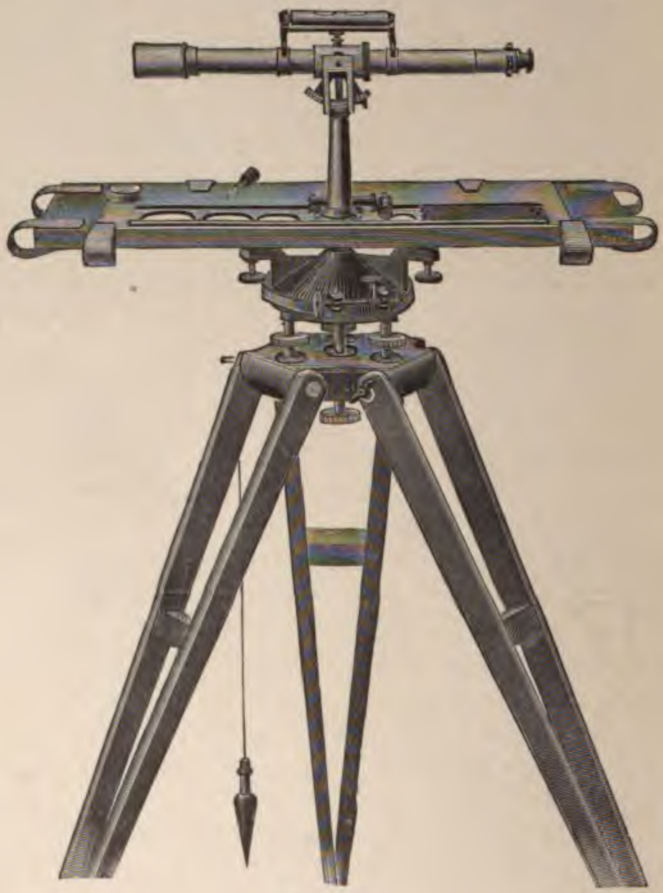


Fig. 124.

Place the ruler upon a smooth surface, and draw a line along its edge, and also lines at its ends. Reverse the ruler on these lines, and draw another line along its edge. If these two lines coincide, the ruler is straight.

2nd. *To make the plane of the table horizontal when the bubbles are in the center of the tubes.* Assuming the table to be plane, set the alidade in the middle of the table, level by means of the leveling screws, draw lines along the edge and ends of the ruler, and reverse the alidade on these lines. If the bubbles remain in the center of the tubes, they are in adjustment. If they do not, correct one-half of the error by means of the leveling screws and the remainder by means of the capstan-headed screws of the level tubes. Repeat the operation until the bubbles remain in the center of the tubes in both positions of the alidade.

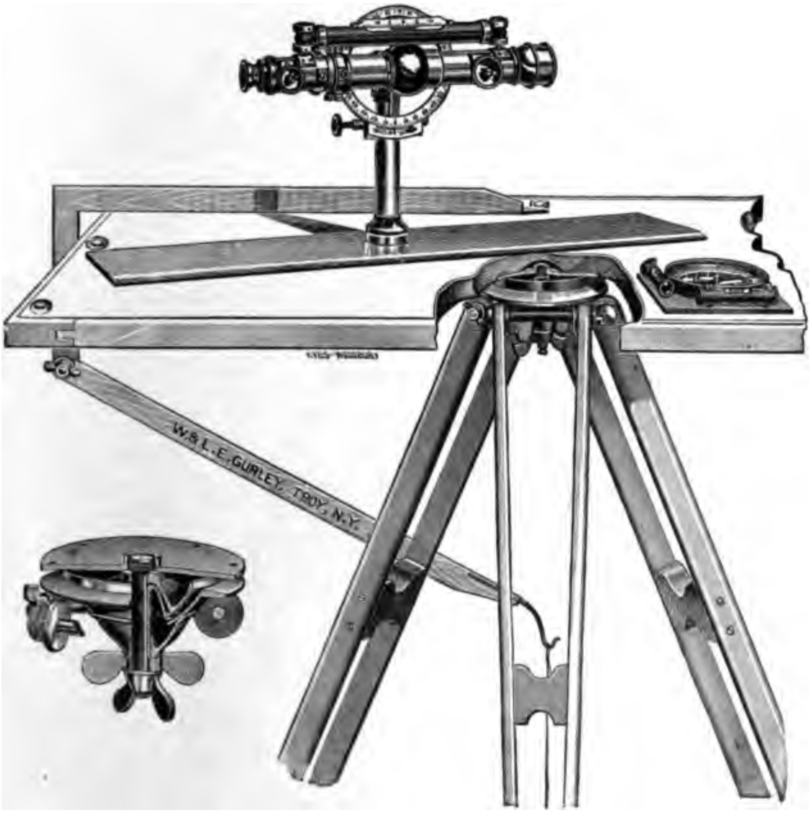

W.&L.E.GURLEY, TROY, N.Y.

Fig. 124*a*.

3rd. *To make the line of collimation perpendicular to the horizontal axis of the telescope.*

Level the table and point the telescope towards some small and well-defined object. Remove the screws which confine the axis of the telescope in its bearings, reverse the telescope in its bearings, that is, change the axis end for end, being careful not to disturb the position of the alidade upon the table, and again sight upon the same object. If the intersection of the cross hairs bisects the object, the adjustment is complete. If not, correct one-half of the error by means of the horizontal screws attached to the reticle. Sight on the object again and repeat the operation until the line of collimation will bisect the object in both positions of the telescope.

4th. *To make the line of collimation parallel to the axis of the bubble tube.*

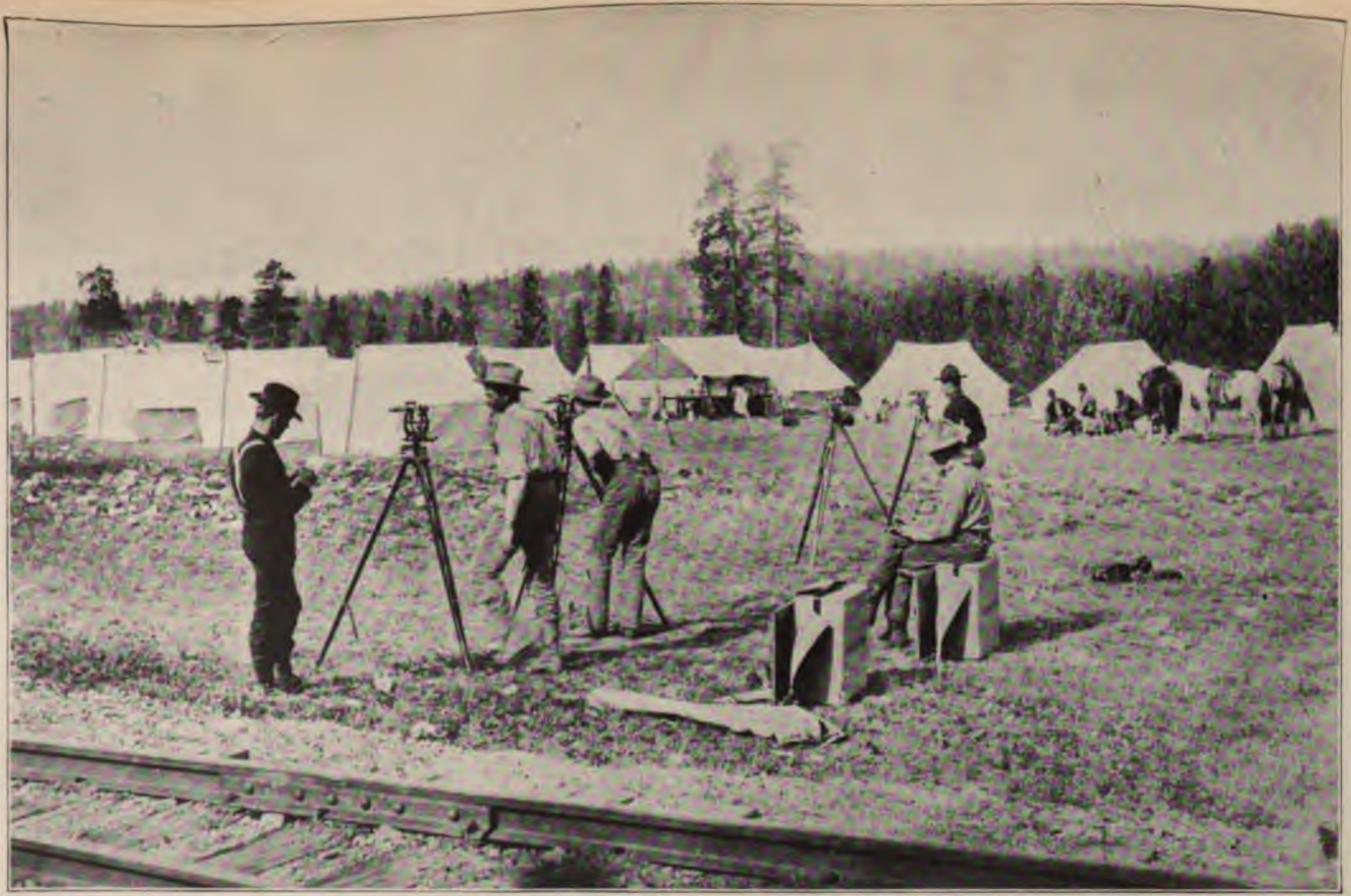
Attach the longitudinal striding level to the telescope and carry out the adjustment by the "peg" method as described for the transit.

5th. *To make the horizontal axis of the telescope parallel to the plane of the table.*

Level the table and point the telescope to a well-defined mark at the top of some tall object, as near as possible consistent with distinct vision. Turn the telescope on its horizontal axis, and point to a small mark at the base of the same object. Draw lines on the table at the edge and ends of the ruler. Reverse on these lines, point the telescope to the lower object and turn the telescope upon its horizontal axis. If the line of collimation again covers the higher point, the adjustment is complete. If it does not, correct one-half of the error by means of the screws at one end of the horizontal axis.

6th *To make the vertical arc or circle read zero when the line of collimation is horizontal.*

Level the table and measure the angle of elevation or depression of some object. Remove the table to the object, level as before, and measure the angle of depression or elevation of the first point Half the difference, if any, of the readings is the error of the adjustment. Correct this by means of the screws attached to the vernier plate, and repeat the operation until the angles as read from the two stations are equal.



RENDEZVOUS CAMP OF THE UNITED STATES AND CANADA BOUNDARY SURVEY AT GATEWAY, MONTANA

Testing the transits.

Use. The plane-table is used for the immediate mapping of a survey made with it, no angles being measured, but the direction and length of lines being plotted at once, upon the paper. The simplest case is the location of a number of points from one central point, called the method of radiation. The table is "set up" so that some convenient point upon the paper is over a selected spot upon the ground and is then clamped in azimuth. Mark the point upon the table by sticking a needle into the board. Now bring the edge of the alidade in contact with the needle and swing it around until the line of sight, which is parallel to the edge of the ruler, is directed to the point to be located. Having determined the scale of the plat, a line is drawn along the edge of the ruler to scale, equal to the distance to the desired point, such distance having been measured either with the tape or stadia. In the same way locate all of the other points, which may include houses, trees, river banks, etc. If the plane-table is set up in the interior of a field at a point from which all of the corners are visible, the corners can be thus located and after being connected, there results a plot of the area. Instead of occupying a point in the interior of the field, one corner may be selected from which all of the others are visible, or a point outside of the field may be chosen from which to measure the lines to the several corners. Evidently from such a survey, data is lacking from which to calculate the area, and either the map must be scaled for additional data or the area measured with the planimeter.

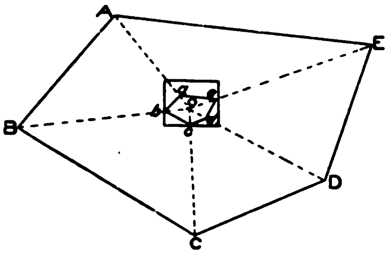


Fig. 125.

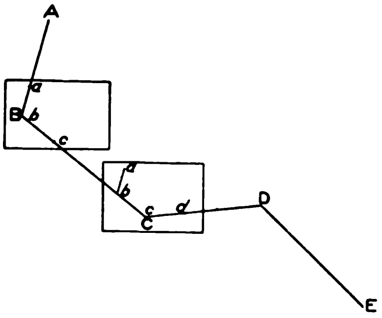


Fig. 126.

The Fig. 125 illustrates the method of surveying a closed area by the method of radiation. The plane-table is at the point e and drawn to an exaggerated scale. The area *abcde* representing to scale, the area ABCDE. It may be desirable to set up the table at some other point, as for instance one of the corners of the field, and run out some of the lines to the other corners as a check upon the work.

Traversing, or the Method of Progression. This method is practically the same as the method of surveying a series of lines with the transit, but requires that all of the points be accessible. It is the best method of working as it provides a complete check upon the survey.

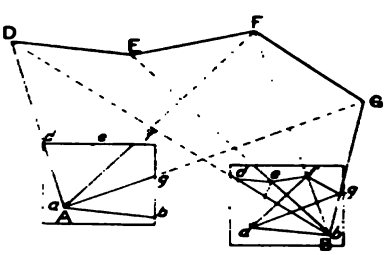


Fig. 127.

Let ABCDE, Fig. 126, be the series of lines to be surveyed by *traversing*. Set up the table at B, the second angle of the line, so that the point *b* upon the paper will be directly over the point B upon the ground. (The point *b* should be so chosen as to leave room upon the paper for as much of the traverse as possible.) Stick a needle at the point *b* and place the edge of the alidade against it. Swing the alidade around until the line of sight covers the point A. Measure BA and lay it off to the proper scale as *ba*. Now turn the alidade around the point *b* and sight to and measure the distance BC and plot it to scale as *bc*. Remove the instrument to *c* with the point *c* upon the paper directly over C upon the ground, and *cb* in the direction of CB. This is difficult to accomplish with the plane-table, but if the plot is drawn to a large scale, it must be done. If the plot is drawn to a small scale, it will be sufficiently accurate to set the table over the point C as nearly as possible in the proper direction and then turn the *board* in azimuth until *b* is in the direction of B. Stick a needle at *c* and check the length of *cb*. Swing the alidade around *c* until the line of sight covers D, measure CD and plot *cd*. Remove to D and proceed as before and so on through the traverse.

If the survey is of a closed field, the accuracy of the work will be checked by the closure of the survey.

The method of progression is especially adapted to the survey of a road, the banks of a river, etc., and often many of the details may be sketched in with the eye.

When the paper is filled, put on a new sheet, and on it, fix two points, such as D and E, which were on the former sheet and from them proceed as before. The sheets can afterward be united so that all points on both shall be in their true relative positions.

Method of Intersection. This is the most rapid method of using the plane-table. Set up the instrument at any convenient point, as A in Fig. 127 and sight to all the desired points as D, E, F, etc., which are visible, and draw indefinite lines in their directions. Measure any line as AB, B being one of the points sighted to, and plot the length of this line upon the paper to any convenient scale. Move the instrument to B so that *b* upon the paper will be directly over B upon the ground, and so that *ba* upon the paper will be in the direction of BA upon the ground as explained under the method of progression. Stick a needle at the point *b* and swing the alidade around it, sighting to all the former points in succession, and draw lines in their direction. The intersection of these two sets of lines to the several points will determine the position of the points. Connect the points as *d*, *e*, *f*, *g*, in the figure. In surveying a field, one side may be taken as the base line. In choosing the base line, care must be exercised to avoid very acute or obtuse angles: 30° and 150° being the extreme limits. The impossibility of always doing this, sometimes renders this method deficient in precision.

TOPOGRAPHICAL SURVEYING.

A topographical map is one showing the configuration of the surface of the ground of the area to be mapped and includes lakes, rivers, and all other natural features, and sometimes artificial features as well.

A topographical survey is one conducted for the purpose of acquiring information necessary for the production of a topographical map of the area surveyed.

Nearly all engineering enterprises involve a topographical survey more or less extended, depending upon the nature and importance of the contemplated work. The construction of an important building may involve a survey of the foundation site to determine the amount of cut and fill; the construction of a bridge will involve a hydrographic survey of a body of water to acquire information in regard to direction and velocity of current, depth of water, nature of bottom, and proper site for piers and abutments. A proposed railroad will not only involve a survey of the line itself, but a topographical survey extending from 200 to 400 feet upon each side. The design of a sewer system or a waterworks system, dams, reservoirs, canals, irrigation channels, tunnels, etc., all involve topographical surveys.

In what follows it is intended to outline the methods of conducting field operations, based partly upon the nature and importance of the problem involved, and partly upon the instruments used. The different methods of representing topography and the involved drafting-room work will be fully treated in Topographical Drawing.

The field operations, in so far as the methods and instruments are concerned, may be classified as follows:

1. Sketching by the eye, without or with the tape for measuring distances.
2. Sketching with the aid of the Locke hand-level or clinometer, horizontal distances being measured either by pacing or with the tape.
3. Determining the elevation of points with the wye-level, horizontal distances being determined either with the stadia or tape.
4. Determining points with the transit and stadia.
5. Topographical sketching with the plane-table and stadia.
6. Photography.
7. Triangulation.

It is evident that the first method is entirely lacking in accuracy, and such work should be done only when speed is the most important consideration, only the roughest approximation to the topographical features being attempted; contour lines cannot be located. Work of this nature is of value principally for purposes of promoting an enterprise; artistic, showy plates being desired. Little can be said descriptive of the manner of carrying out the field work, since this will require considerable artistic ability as well as the ability to "see" things and estimate distances. Comparatively few men possess the ability to carry out topography of this nature. It necessarily follows that the work must be done entirely by sketching in the field, and for this purpose the following equipment is needed :

2 or 3 medium pencils, kept well sharpened.
Rubber eraser.
Thumb-tacks.
Several sheets of drawing paper, 14" × 14".
One light drawing board, 15" × 15".

A pocket compass will be useful in determining the bearing to prominent objects to tie in the stations of the survey. A Locke hand-level or Abney clinometer will also be useful for finding approximate heights, and either of these instruments can be readily carried in the pocket. It will be more convenient to have the paper cross-ruled into one-fourth inch squares, the center line being ruled in red, but if drawing paper is used, it will be necessary to add an engineer's scale to the equipment. The back of the drawing board should be fitted with a leather pocket, with flap and button, in which the blank sheets and the finished topographic sheets should be kept. A strap attached to the board and to go over the shoulder, will prove a great convenience. A waterproof cover should be provided to protect the board and sheets in case of rain.

A compass or transit survey forms the backbone of the topography, and the sketching should include an area upon each side of the line so surveyed, and running parallel with it.

A separate sheet should be used for each course (by course is intended the straight line from one turning point to the next), no matter how short it may be. Begin at the bottom of the sheet and sketch the topography up the sheet, that is, in the direction of the progress of the survey, and number the sheets in order. Begin each new sheet with the same station that ended the preceding sheet. After the field work is completed, the sheets can be laid down in order, the angles between their center lines corresponding to the deflection angles as given by the transit notes of the survey. The topography can now be traced upon tracing cloth in a continuous sheet. The method above outlined will result in a saving of time, especially in working up the topographic plat.

The second method commends itself in connection with a preliminary survey of a highway, steam or electric road, irrigation channels, canals, etc. The equipment should be as follows:

1 or 2 straight edges, about 12 feet in length.
1 or 2, 100-foot steel tapes.
1 or 2 plumb-bobs.
1 pocket compass.
2 or 3 medium pencils, kept well sharpened.
Rubber eraser.
Thumb-tacks.
Several sheets of drawing paper or cross-section paper, 14" × 14".
One light drawing board, 15" × 15" with waterproof cover.

The topographic party should be made up of the topographer and one or two assistants, depending somewhat upon the nature of the survey and the country traversed. If the country permits of rapid progress of the transit and level party, two assistants will be necessary to keep the topography abreast of the survey. Rapid work may, however, be done with one assistant, provided the topography does not extend more than 200 feet each side of the transit line.

The Abney clinometer is well adapted for this class of work, on account of its portability, which is an important item in a rough country with steep side slopes. It can be used in the same way as the Locke hand-level, if necessary, but is a more generally useful instrument, as is described in Part 1. The straight edge should be of well-seasoned, straight-grained material, as light as possible, but so constructed as to prevent warping. It should be divided into spaces of one foot each, painted alternately red and white. The tapes should be of band steel, as they are subjected to rough usage, and they should be divided to feet and tenths at least. A plumb-bob is necessary for plumbing down the end of the tape on steep slopes. The pocket compass is a *necessary* adjunct in work of this character. The drawing paper should preferably be cross-section paper ruled into one-fourth inch squares with a heavy center line in red, but if ordinary drawing paper is used, it will be necessary to include in the outfit an engineer's scale, by means of which distances may be platted upon the sheet. Enough of these sheets should be carried to cover a day's work, but no more. The drawing board should be fitted up as described under the previous method.

Method of Procedure. The transit line furnishes, of course, the backbone of the survey, and the topography will be taken for the proper distance upon each side of this line, by locating points both as to distance and elevation, upon perpendiculars from the transit stations. In rough country, it may be necessary to locate these points intermediate between the transit stations. Before starting out upon a day's work it is necessary to procure from the level party, the elevation of the transit stations, or if the topography keeps pace with the transit survey, the elevation may be obtained from the leveler at each station. For points intermediate between transit stations, the elevations may be gotten closely enough with the clinometer or hand-level. The number of each station as well as its elevation, should be noted upon the topographic sheet, and the topography will include the location of contour lines, at proper vertical intervals, as well as all streams, lakes, property lines, etc. An example showing the method of keeping the field notes, will at the same time best serve to explain the methods of conducting the survey.

Beginning with station 0 at the bottom of the sheet, the number and elevation of the station are noted. See Fig. 128. Sending the assistant out upon one side of the transit line and at right angles thereto, he holds the rod at points to be designated by the topographer, the distances to be determined by pacing, or with the tape, and the elevations determined either by sighting upon the rod with the clinometer, or by laying the straight edge upon the ground at right angles to the line and applying the clinometer to it to determine the slope, from which elevations can at once be determined. Contour points are then readily interpolated and the distance out platted to scale upon the sheet and a note made of the elevation of the contour lines. If a lake or stream intervenes within the limits of the topographic survey, determine the distance to and elevation of the shore line and plat upon the sheet. Determine points upon the other side of the transit line in the same way.

If one or more contour lines cross the transit line between stations, determine the points of crossing and plat the points upon the sheet, to scale, as shown between stations 0 and 1. It will be noticed in this case that the elevation of station 0, is 138 feet and of station 1, is 141 feet. If contours are to be taken at vertical intervals of five feet, it is apparent that the 140-foot contour line must cross the transit line between these stations. If the slope of

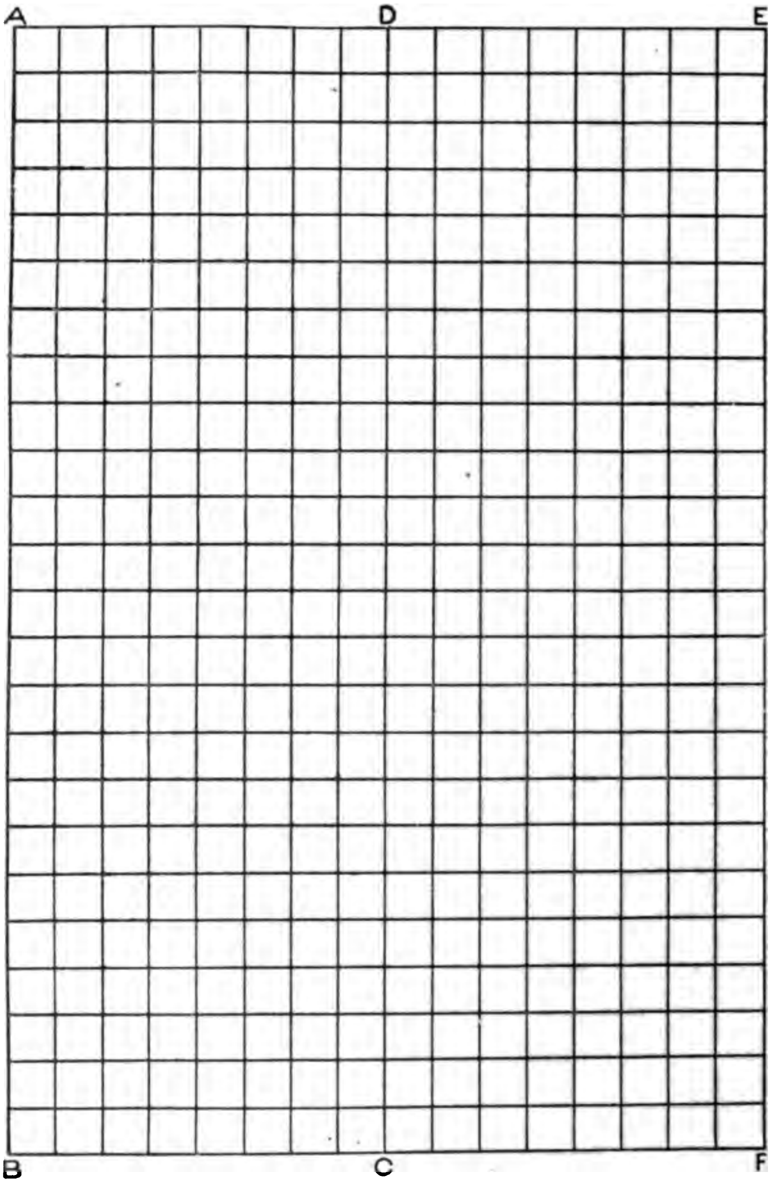


Fig. 128.

the ground is uniform, the point of crossing may be taken at two-thirds of the distance from 0 to 1. Otherwise, locate the point with the clinometer.

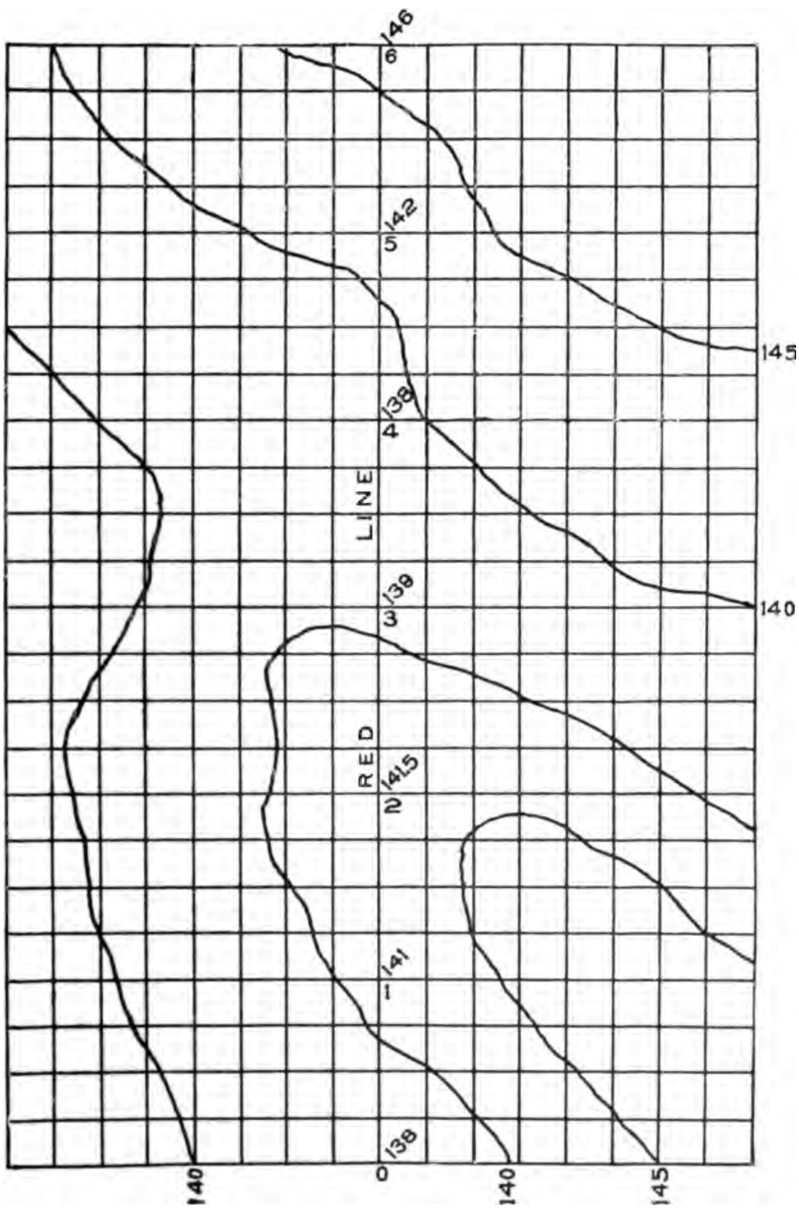


Fig. 128.

Now go to station 1 and locate contour points and other topographic features as before described, and connect points in the same contour line, sketching in the curve of the line with the eye. Use a separate sheet for each portion of the transit line from turning point to turning point; this will require that the turning points appear upon two consecutive sheets. Likewise, if the length of the line between turning points is too long to be platted upon a single sheet, begin the second sheet with the same station that completed the first sheet and so continue throughout the survey. As each sheet is completed, number it and return to the pocket on the back of the drawing board. The pocket compass should be used for determining the bearing of property lines, roads, streams, etc., crossed by the survey, and to take the bearings to prominent objects.

The topographic sheets should be filed away in such a manner as to make them easily accessible at any time, as the engineer in charge of the transit survey may wish to consult them from time to time. The office work of preparing the topographic plat can be very expeditiously carried out as before described.

The use of the wye-level as a topographic instrument is limited, but for certain kinds of work the instrument is the most satisfactory, as for instance, the survey of a dam-site; the survey of a reservoir-site; the survey of a town preparatory to planning sewer and waterworks systems and the planning of street pavements.

The instrument should be fitted with stadia wires for measuring horizontal distances, and this will usually prove a great convenience, resulting in saving of both time and expense. A steel tape should, however, be included in the equipment for field work, for the purpose of checking measurements with the stadia. In addition to the above there should be provided, the following equipment:

Self-reading level rod, capable of being read to hundredths of a foot.
Hatchet.
Marking crayon.
2 or 3 medium pencils, kept well sharpened.
Plumb-bob.
Rubber eraser.
Portable turning point.

The method of using the level rod in connection with the stadia for measuring distances has been fully discussed in Part II.

The portable turning point will prove of great convenience and may be made from a triangular piece of thin steel, with the corners turned down to project about one inch.

If the level is to be used with the tape, the party will be made up of the levelman, two tapemen and a rodman, unless the nature of the work will permit of the rodman carrying the rear end of the tape. If the stadia is used for measuring distances, only the rodman will be required in addition to the levelman. The levelman carries the note book and enters into it all rod readings both for elevation and distances. These notes should be entered upon the left-hand page, the right-hand page being reserved for notes and sketches, which should be as full as possible. The levelman should cultivate the practice of calculating the elevations of the stations as the work progresses, at least of the turning points and bench-marks, in order that the results may be checked and errors discovered at once and corrected. If this work is left to be afterward carried out in the office, errors may be discovered that may require considerable time to locate and correct.

If the area to be surveyed is, for instance, a reservoir site, it will be found most convenient to cover the area with a system of rectangles as shown in the figure, the parallel lines being spaced from 200 to 400 feet apart as may be most desirable. These lines should be run in with the transit, stakes being set at the intersections of the cross lines, or if the area is not very extended and is comparatively level, by means of the level itself, the perpendicular distances between the parallel lines being measured with the tape.

These lines having been laid down, the next step is to establish a system of bench-marks over the area. Begin by establishing a "standard" bench-mark at some central point upon a permanent object, easily identified, and from thence radiate in all directions, returning finally to the original bench-mark for purposes of checking. Having located and satisfactorily checked the bench-marks, begin by running the level over all the lines running in one direction, as from A to B, back from C to D and so on, taking rod readings at every fifty or one hundred feet, in addition to the readings at the stakes at intersections of cross lines. It is to be understood that stakes are not to be driven at the intermediate points. Next run the level over the lines at right angles to the former ones and in the same way, checking the levels at intersections. Advantage should be taken of every opportunity to check upon bench-marks previously located, and to establish others.

In keeping the field records, the notes of the two sets of lines should be kept in separate books ; that is to say, if, for instance, one set of lines run north and south, and, therefore, the other east and west, the notes of the north and south lines should be entered in one set of books and the notes of the east and west lines in another set, and a note should be made of the direction in which a line is run, as from north to south or from east to west.

In conducting a survey for the preparation of a topographical map necessary to the design of a sewer or waterworks system, much the same method is to be followed, but now the streets and alleys take the place of the rectangular system referred to above. As before, all the streets and alleys running in parallel directions are to be gone over in a systematic way, readings being taken fifty or one hundred feet apart in addition to street and alley intersections. (By street and alley intersections is intended the intersections of the center lines, the lines of levels being run along these center lines.) If a fairly accurate map of a town is available, the distances measured with the tape along the center line of the streets and alleys will serve as a check upon the map. If, however, discrepancies occur or there is no map available, it will be necessary to use the transit for staking out street lines and for determining the relative directions of these lines. It follows that the topography of the ground between streets and alleys can only be approximated, but sufficient points accurately determined will have been established to permit the platting of a contour map, from which the system can be laid down.

The office work involved in the survey of an area, as above described, consists in preparing profiles of the level lines and preparing a plat of the lines surveyed. From the profiles the contour points can be laid down in their proper position upon the plat, and as each point is laid down, its elevation should be noted in pencil, and after all the points have been platted, the points in the same contour line can be connected—preferably free-hand—producing the contour map. The scale to be adopted will depend upon the nature of the work, but should be as large as possible, consistent with the convenient handling of the map.

Transit and Stadia. The method by transit and stadia is of more general application than the preceding method, points being located by "polar co-ordinates," that is to say, by direction and distance from a known point, the elevation being determined at the same time.

Method of conducting field operations. If the area to be surveyed is small, the preceding method, based upon a system of rectangles, will prove satisfactory, and the elevations of the corners and salient points can be determined at the same time that the lines forming the rectangles are being laid down. Especial care should be taken to check the elevations of the corners.

In making a survey for a sewer or a waterworks system, the transit and stadia method will be found efficient, especially in cases where no survey has previously been made, the map, if it exists at all, having been compiled from the records in the County Recorder's office. The bench-marks necessary in a survey of this kind, however, should be established with the wye-level, and it may be desirable to determine the elevation of street intersections in the same way.

If the area to be surveyed is too large, or of uneven topography, proceed as follows: Choose a point, as the intersection of two streets, the corner of a farm, or an arbitrary point conveniently located and drive a stake firmly at this point, "witnessing" it from other easily recognized points or stakes. The transit should be set over this point with the vernier reading zero, and the instrument pointed by the lower motion in the direction of the meridian. This may be the true meridian previously determined, the magnetic meridian as shown by the needle, or an arbitrary meridian assumed for the purpose of the survey. It will generally be more satisfactory to run out a true meridian by means of the solar attachment, but in any event the direction of the line taken as a meridian should be defined by stakes, firmly driven into the ground. and "witnessed" by stakes or other objects easily recognized. The elevation of the starting point, if not known, is assumed and recorded in the notebook. A traverse line should now be run, its position and direction chosen with a view to obtaining from each station the largest possible number of pointings to salient features of the area under survey, and these pointings are taken while the instrument is set at any station, and before the traverse is completed.

The length of each course is measured with the stadia, and together with the azimuth and the vertical angle, it should be recorded in the notebook. The length, azimuth, and vertical angle of each course should be read from both ends to serve as a check. The additional pointings taken from each course of a traverse are usually called "side shots", and for each there are required the distance, azimuth, and vertical angle. These will locate the point and determine its elevation.

The method of using the stadia has already been quite fully discussed in Part II., and need not be repeated.

The points selected for side shots should be such as will enable the contours to be platted intelligently and accurately upon the map of the area under survey. They should be taken along ridges and hollows and at all changes of slope. They should be taken at frequent intervals along a stream to indicate its course, or along the shore of a lake. It is usually required that the location of artificial structures, such as houses, fences, roads, etc., be determined that they may be mapped in their proper position. Pointings, therefore, should be taken to all fence corners and angles, and to enough corners and angles of buildings, to permit of their being platted. Sufficient points should be taken along roads to determine their direction. Wooded lands, swamps, etc., may be indicated by pointings taken around their edges. In addition to the notes above described, the recorder should amplify the notes with sketches, to aid the memory in mapping.

The traverse, of course, forms the backbone of such a survey, and the accuracy of the resulting topographical map will depend upon the degree of care bestowed upon running the courses. Over uneven ground, it is often desirable to run a secondary traverse from the first, for the more rapid and accurate location of points.

The organization of a party will depend upon the nature of the country traversed and of the results required. Changes in the make-up of parties, as given below, will suggest themselves for any special work.

For economy and speed, the party for taking topography with transit and stadia will consist of a transitman or observer, a recorder in charge of the notebook, who should be capable of making such sketches as are necessary, and two to four men with stadia rods. The greater the distances to be traversed by the stadia men between points taken, the greater number the observer can work to advantage. One or two axemen may be employed if clearing is to be done.

The party may be reduced to two men—one to handle the instrument, record notes and make sketches, the other to carry the rod.

The Plane Table and Stadia. The plane table is an instrument intended for topographic purposes only and is used for the immediate mapping of a survey made with it, no notes of angles being taken, but the lines being platted at once upon the paper. The use of the plane table has been fully described. In topographical work over an extended area, it may be used for filling in details, based upon a previous traverse made with a transit, or based upon a system of triangulation as will be described. Over small areas, the traverse itself may be run with the plane table and the details filled in at the same time. It is the standard instrument of the United States Geological Survey and is largely used upon the United States Geodetic Survey.

The points in favor of the plane table are : Economy, since the map is made at once without the expense of notes and sketches, and as the mapping is all done upon the ground to be represented, all of its peculiarities and characteristics can be correctly represented.

On the other hand, the plane table is an instrument useful only for taking topography ; the rodmen are idle while the mapping is being done ; the instrument is more unwieldy than the transit, particularly upon difficult ground ; the record of the work for a long period is constantly exposed to accident ; the distortion of the paper with the varying dampness of air, introduces errors in the map ; while the area exposed makes it too unstable to use in high winds.

The organization of a party for the taking of topography, using the plane table, is much the same as with the transit and stadia; however, on account of the weight of the instrument, means of transportation must be provided.

A less number of rodmen can be employed than with the stadia, owing to the time required for mapping.

An observer, a man to reduce stadia notes and sketch topography around points determined by intersection or stadia from the plane table station, and one rodman, will make the minimum working party, in addition to which, axemen and a team for transportation will be required.

Photography. The following is taken from Gillespies Surveying (Staley).

"Photography has long been successfully employed by European engineers, notably those of Italy, for the purpose of taking topography. The Canadian Government has also employed it successfully in the survey of Alaska.

The recommendation of this method is the great saving of time in the field, while giving topographic features with all the accuracy required for maps to be platted on a scale of 1 to 25,000.

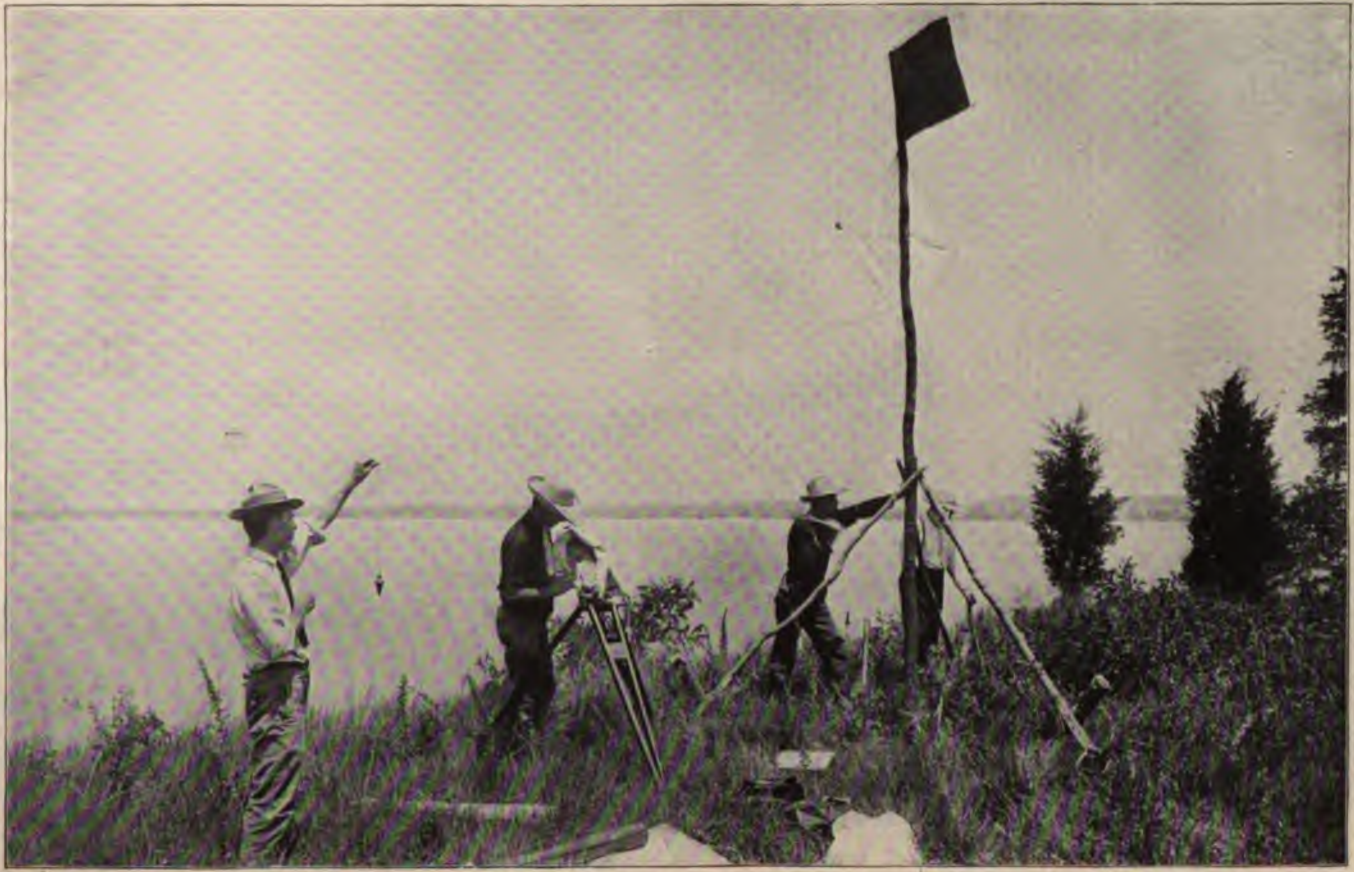
M. Javary states that the maximum error both for horizontal distances and elevations, using a camera with a focal length of twenty inches and a microscope in examining the points, was only 1 in 5,000 as deduced from a number of cases.

M. Laussedat, in his work, found that this method did not require more than one-third the time necessary by the usual methods.

This makes it especially suitable in all mountainous regions, where so much time is lost in getting to and from stations, that little is available for observations and sketching.

A single occupation of a station with photographic apparatus would suffice to complete work that with the ordinary methods would require several days."

Instruments. The ordinary camera may be used, if it is provided with a level. A tripod head for leveling the instrument, and a roughly graduated horizontal circle for reading the direction of the line of sight, when photographing different parts of the horizon, are convenient attachments.



PLUMBING A TEMPORARY SIGNAL

A camera is sometimes used upon a plane table, the record of the work being made upon the paper in connection with a set of radial lines drawn from the point representing the station occupied.

Many special forms of instrument combining the camera and theodolite have been devised, some one of which should be used if work of this kind is to be undertaken on a large scale. For a description of these instruments, and a complete treatise on this subject, comprising a discussion of the requirements of the apparatus, the fundamental principles of photography, methods of field work, forms of notes, reduction of notes and making of the map, together with the bibliography of the subject, see United States Coast and Geodetic Survey Report, 1893, Part II., Appendix 3.

The camera tripod as ordinarily constructed is too unstable for purposes of topographic surveying, and it is desirable to have a tripod constructed especially for this class of work. Glass plates are heavy and awkward to carry aside from their fragile nature. Cut films can be procured in any of the standard sizes, and as they are light and stand rough handling and give ordinarily as good results as the glass plates, they are to be preferred. Their cost is about double that of the glass.

TRIANGULATION.

This method of surveying is sometimes called "Trigonometric Surveying" and sometimes "Geodetic Surveying", though this latter is properly applied only when the area to be surveyed is so extensive that allowance must be made for the curvature of the earth. Since this instruction paper is devoted to Plane Surveying only, the curvature of the earth will be neglected.

Triangulation, or Triangular Surveying, is founded upon the method of determining the position of a point at the apex of a triangle of which the base and two angles are measured. Thus in Fig. 129 the length of the base line AB is measured and the angles PAB and PBA are measured, from which can be calculated the lengths of the sides PA and PB. This calculated length of PA will then be taken as the side of a second triangle, and the angles PAC and PCA measured, from which the other sides of the triangle can be calculated. By an extension of this principle, a field, farm, or a country can be surveyed by measuring a base line only, and calculating all of the other desired distances, which are made the sides of a connected series of imaginary triangles whose angles are carefully measured.

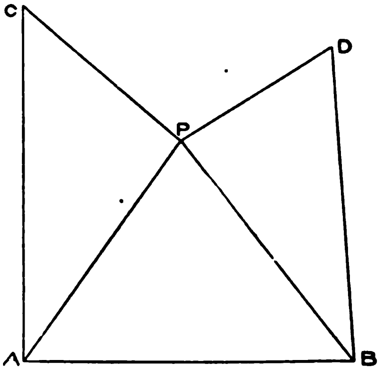


Fig. 129.

Measuring the base line. For a base line, a fairly level stretch of ground is selected, as nearly as possible in the middle of the area to be surveyed, and a line from one thousand feet to one-half mile, or longer, is very carefully measured. The ends of this line are marked with stone monuments or solid stakes. If the survey is of sufficient importance, the ends of the base line and the apexes of the triangles should be permanently preserved by means of stones not less than six inches square in cross-section and two feet long, these stones being set deep enough to be beyond the disturbing action of frost. Into the top of this stone should be leaded a copper bolt about one-half inch in diameter, the head of the bolt being marked with a cross to designate the exact point. The point may be brought to the surface by a plumb-line for use in the survey. The location of each monument should be fully described with reference to surrounding objects of a permanent character, so as to be easily recovered for future use.

The measurement of the base line for the areas of limited extent should be made with a precision of from one in five thousand to one in fifty thousand, depending upon the scale of the map, the extent of the area under survey, and the nature and importance of the work.

The two ends of the base line having been determined and marked, the transit is set over one end and a line of stakes ranged out between the two ends, especial care being taken to make the alignment as perfect as possible. These stakes should be not less than two inches square, driven firmly into the ground, preferably at even tape lengths apart, or at least at one-half or one-quarter tape lengths, center to center; the centers should be marked by fine scratches upon strips of tin or zinc tacked to the top of the stakes.

For ordinary work the base line may be measured with a tape, notes being made of the temperature, pull, grade, and distances between supports, the tape having been previously standardized. For a degree of precision, such as is attempted upon the work of the United States Coast and Geodetic Survey, more refined methods are used, but as this properly belongs to geodetic surveying, it is unnecessary to consider it here.

Measuring the angles. After establishing and measuring the base line, prominent points are chosen for triangulation points or apexes of triangles, and from the extremities of the base line angles are observed to these points, care being taken to so choose the points that the angles shall in no case be less than 30°, nor more than 120°. The distances to these and between these points are then calculated by trigonometric methods, the instrument being then placed at each of these new stations and angles observed from them to still more distant stations, the calculated lines being used as new base lines. This process is repeated and extended until the entire district included in the survey is covered with a network of "primary triangles" of as large sides as possible. One side of the last triangle should be so located that its length can be determined by direct measurement as well as by calculation; the accuracy of the work can thus be checked. Within these primary triangles secondary or smaller triangles are formed to serve as the starting points for ordinary surveys with the transit and tape, transit and stadia, plane table, etc., to fix the location of minor details. Tertiary triangles may also be formed.

When the survey is not very extensive, and extreme accuracy is not required, the ordinary methods of measuring angles may be employed. Otherwise there are two methods of measuring angles, called, respectively, the method of repetition and the method by continuous reading. When an engineer's transit is used for measuring angles, the method by repetition is the simplest and best and is carried out as follows: The vernier is preferably set at zero degrees and then by the lower motion turned upon the left-hand station; the lower motion is then clamped and the instrument turned by the upper motion upon the right-hand station: the upper motion is then clamped and the instrument turned by the lower motion upon the left-hand station; lower motion clamped and instrument again turned by upper motion upon right-hand station. This process is repeated as often as may be necessary to practically cover the entire circle of 360° and the circle is then read. This reading divided by the number of repetitions will give the value of the angle.

Now reverse the telescope and repeat the observations described above, but from *right* to *left;* the readings being taken in both directions to eliminate errors due to clamping and unclamping and personal errors due to mistakes in setting upon a station. The readings should be taken with the telescope both direct and reverse to eliminate errors of adjustments. Both verniers should be read in order to eliminate errors due to eccentricity of verniers, and the entire circle is included in the operation in order to eliminate errors due to graduation.

The second method, by continuous reading, consists in pointing the telescope at each of the stations consecutively, and reading the vernier at each pointing; the difference between the consecutive readings being the angle between the corresponding points. Thus in Fig. 130 with the instrument at zero, the telescope is first directed to A and the vernier is read; then to B, C, D, E, etc., in succession, the vernier being read at each pointing. The reading of the vernier on A, subtracted from that on B, will give the angle AOB and so on. It is necessary in this method, to read both to the right and to the left, and with the telescope both direct and inverted. Since each angle is measured on only one part of the limb, it is necessary after completing the readings once around and back, to shift the vernier to another part of the limb and repeat the readings in both directions, and with the telescope direct and inverted. This is done as many times as there are sets of readings. Each complete set of readings to right and left, with

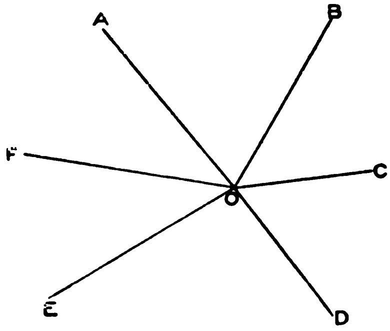


Fig. 130.

the telescope direct and inverted, gives one value for each angle.

The lengths of the sides of the triangles should be calculated with extreme accuracy in two ways if possible, and by at least two persons. Plane trigonometry may be used for even extensive surveys; for though these sides are really arcs and not straight lines the error under ordinary circumstances will be inappreciable.

Radiating Triangulation. This method as is illustrated in Fig. 131 consists in choosing a conspicuous point O, nearly in the center of the area to be surveyed. Other points as A, B, C, D, etc., are so chosen that the signal at O can be seen from all of them, and that the triangles ABO, BCO, etc., shall be as nearly equilateral as possible. Measure one side, as AB for example, and at A measure the angles OAB and OAG; at B measure the angles OBA and OBC; and so on around the polygon. The correctness of these measurements may be tested by the sum of the angles. It will seldom be the case, however, that the sum of the angles will come out just even, and the angles must then be adjusted, as will be explained later. The calculations of the lengths of the unknown sides are readily made by the usual trigonometric methods: thus in the triangle AOB, there are given one side and all of the angles of the triangle from which to calculate AO and BO. Similarly all of the triangles of the polygon may be solved, and finally the length of OA may be measured and compared with the calculated length, as found from the first triangle.

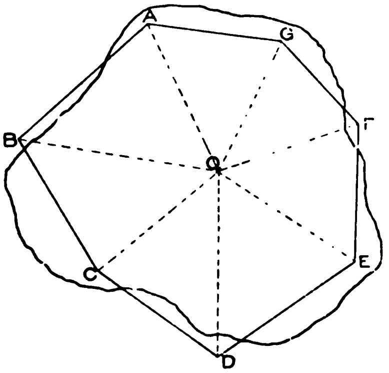


Fig. 131.

A farm or field may be surveyed by the previously described method, but the following plan will often be more convenient: Choose a base line as AB within the field and measure its length. Consider first the triangles which have AB for a base, and the corners of the field for vertices. In the triangle ACB for example (see Fig. 132), we measure the angles CAB and CBA and the length of the base line AB We can therefore calculate the length of AC and BC. Next consider the field as made up of triangles with a common vertex A. In each of them, two sides and the included angle are given, to find the third side. If now the point B at the other end of the base line be taken for a common vertex, a check will be obtained upon the work.

A field or a farm or any inaccessible area such as a swamp, a lake, etc., may be surveyed without entering it. For a farm or any area permitting unobstructed vision, it will only be necessary to choose a base line AB, from which all of the corners of the farm, or all of the salient points of the area, can be seen. Take their bearings, or the angles between the base line and their directions. The distances from A and B to each of them can be calculated as described, and the figure will then show in what manner the content of the field is the difference between the contents of the triangles having A or B for a vertex, which lie outside of it, and those which lie partly within the field and partly outside of it. Their contents can be calculated, and their difference will be the desired content. See Fig. 133. Evidently the entire area included between the corners of the field and the base line is the sum of the triangles A2B, 2B3 and 3B4. Subtracting from this sum the areas of the triangles 2A1, 1AB, 1B6, 56B and 5B4, there will remain the required area of the field, 123456.

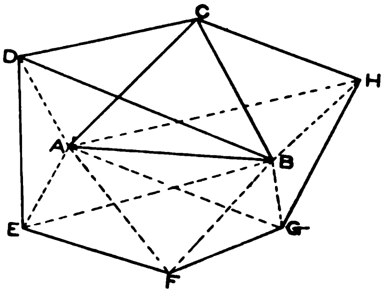


Fig. 132.

In all of the operations which have been explained, the position of a point has been determined by taking the angles, or bearings, of two lines passing from the two ends of a base line to the unknown point, but the same determination may be effected inversely by taking from the point the bearings by compass of the two ends of the base line or any two known points. The unknown point will then be fixed by plotting from the two known points, the opposite bearings, for it will be at the intersection of the lines thus determined.

The determination of a point by the method founded on the intersection of lines, has the serious defect that the point sighted to will be very indefinitely determined if the lines which fix it meet at a very acute or a very obtuse angle, which the relative position of the points observed from and to often render unavoidable. Intersections at right angles should therefore be sought for, so far as other considerations will permit.

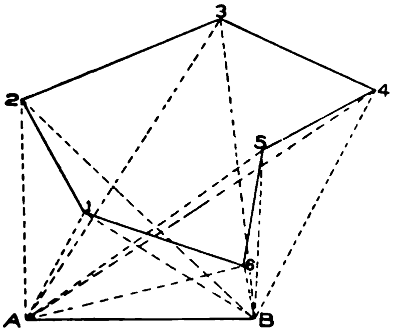


Fig. 133.

Adjusting the Triangle. All of the angles of a given triangle are measured. If but two have been measured, and the third computed, the entire error of measurement of the two angles will be thrown into the third angle. It will be found, upon adding together the measured angles of a triangle, that the sum of the three angles is almost invariably more or less than 180°. With the engineer's transit the error should be less than one minute. If there is no reason to suppose that one angle is measured more carefully than another, this error should be divided equally among the three angles of the triangle, and the *corrected* angles are used in computing the azimuths and lengths of the sides. This distribution of the error is called "adjusting" the triangle. With the large systems of extensive geodetic surveys much more elaborate methods are employed, since a large number of triangles must be adjusted simultaneously so that they will all be geometrically consistent, not only each by itself, but one with another.

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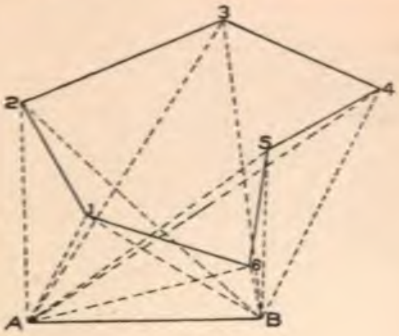

Fig. 133.

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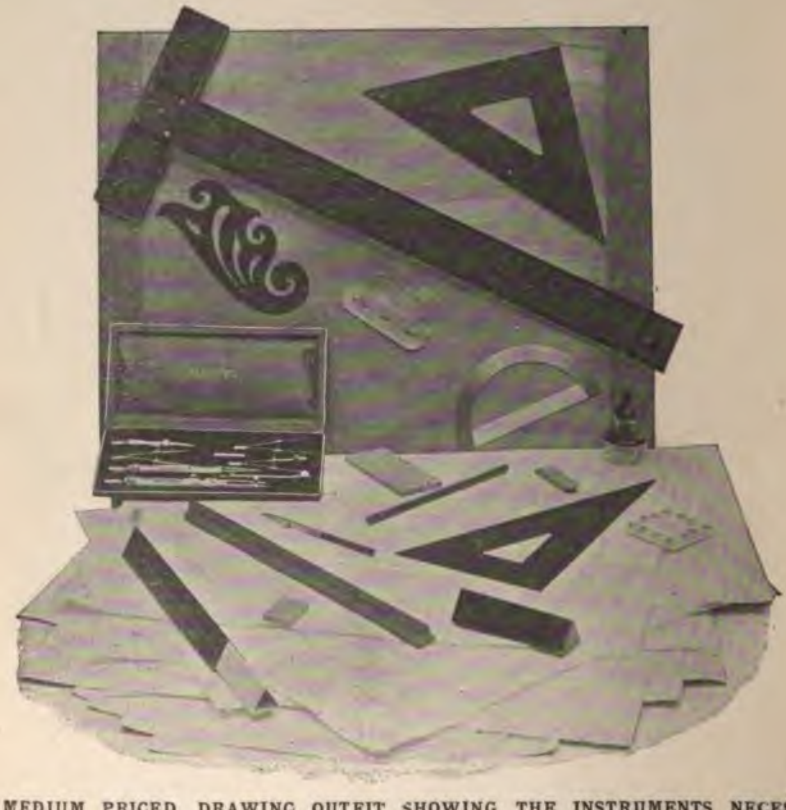

MEDIUM PRICED DRAWING OUTFIT SHOWING THE INSTRUMENTS NECESSARY FOR PURSUING A COURSE IN MECHANICAL DRAWING.

MECHANICAL DRAWING

PART I

The subject of mechanical drawing is of great interest and importance to all mechanics and engineers. Drawing is the method used to show graphically the small details of machinery; it is the language by which the designer speaks to the workman; it is the most graphical way to place ideas and calculations on record. Working drawings take the place of lengthy explanations, either written or verbal. A brief inspection of an accurate, well-executed drawing gives a better idea of a machine than a large amount of verbal description. The better and more clearly a drawing is made, the more intelligently the workman can comprehend the ideas of the designer. A thorough training in this important subject is necessary to the success of everyone engaged in mechanical work. The success of a draftsman depends to some extent upon the quality of his instruments and materials. Beginners frequently purchase a cheap grade of instruments. After they have become expert and have learned to take care of their instruments they discard them for those of better construction and finish. This plan has its advantages, but to do the best work, strong, well-made and finely finished instruments are necessary.

INSTRUMENTS AND MATERIALS.

Drawing Paper. In selecting drawing paper, the first thing to be considered is the kind of paper most suitable for the proposed work. For shop drawings, a manilla paper is frequently used, on account of its toughness and strength, because the drawing is likely to be subjected to considerable hard usage. If a finished drawing is to be made, the best white drawing paper should be obtained, so that the drawing will not fade or become discolored with age. A good drawing paper should be strong, have uniform thickness and surface, should stretch evenly, and should neither repel nor absorb liquids. It should also allow considerable erasing without spoiling the surface, and it should lie smooth when stretched or when ink or colors are used. It is, of

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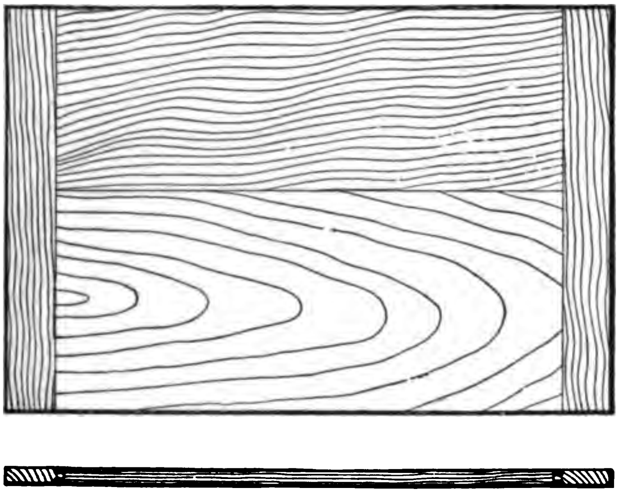
course, impossible to find all of these qualities in any one paper, as for instance great strength cannot be combined with fine surface.

In selecting a drawing paper the kind should be chosen which combines the greatest number of these qualities for the given work. Of the better class Whatman's are considered by far the best. This paper is made in three grades; the *hot pressed* has a smooth surface and is especially adapted for pencil and very fine line drawing, the *cold pressed* is rougher than the hot pressed, has a finely grained surface and is more suitable for water color drawing; the *rough* is used for tinting. The cold pressed does not take ink as well as the hot pressed, but erasures do not show as much on it, and it is better for general work. There is but little difference in the two sides of Whatman's paper, and either can be used. This paper comes in sheets of standard sizes as follows:—

Cap,	13 × 17 inches.	Elephant,	23 × 28 inches.
Demy,	15 × 20 "	Columbia,	23 × 34 "
Medium,	17 × 22 "	Atlas,	26 × 34 "
Royal,	19 × 24 "	Double Elephant,	27 × 40 "
Super-Royal,	19 × 27 "	Antiquarian,	31 × 53 "
Imperial,	22 × 30 "	Emperor,	48 × 68 "

The usual method of fastening paper to a drawing board is by means of thumb tacks or small one-ounce copper or iron tacks. In fastening the paper by this method first fasten the upper left hand corner and then the lower right pulling the paper taut. The other two corners are then fastened, and sufficient number of tacks are placed along the edges to make the paper lie smoothly. For very fine work the paper is usually stretched and glued to the board. To do this the edges of the paper are first turned up all the way round, the margin being at least one inch. The whole surface of the paper included between these turned up edges is then moistened by means of a sponge or soft cloth and paste or glue is spread on the turned up edges. After removing all the surplus water on the paper, the edges are pressed down on the board, commencing at one corner. During this process of laying down the edges, the paper should be stretched slightly by pulling the edges towards the edges of the drawing board. The drawing board is then placed horizontally and left to dry. After the paper has become dry it will be found to be as smooth and tight as a drum head. If, in stretching, the paper is stretched too much it is likely to split in drying. A slight stretch is sufficient.

Drawing Board. The size of the drawing board depends upon the size of paper. Many draftsmen, however, have several boards of various sizes, as they are very convenient. The drawing board is usually made of soft pine, which should be well seasoned and straight grained. The grain should run lengthwise of the board, and at the two ends there should be pieces about 1¾ or 2 inches wide fastened to the board by nails or screws. These end pieces should be perfectly straight for accuracy in using the T-square. Frequently the end pieces are fastened by a glued matched joint, nails and screws being also used. Two cleats on the bottom extending the whole width of the board, will reduce the tendency to warp, and make the board easier to move as they raise it from the table.



DRAWING BOARD

Thumb Tacks. Thumb tacks are used for fastening the paper to the drawing board. They are usually made of steel either pressed into shape, as in the cheaper grades, or made with a head of German silver with the point screwed and riveted to it. They are made in various sizes and are very convenient as they can be easily removed from the board. For most work however, draftsmen use small one-ounce copper or iron tacks, as they can be forced flush with the drawing paper, thus offering no obstruction to the T-square. They also possess the advantage of cheapness.

Pencils. In pencilling a drawing the lines should be very fine and light. To obtain these light lines a hard lead pencil must be used. Lead pencils are graded according to their hardness, and are numbered by using the letter H. In general a lead pencil of 5H (or HHHHH) or 6H should be used. A softer pencil, 4H, is better for making letters, figures and points. A hard lead pencil should be sharpened as shown in Fig. 1. The wood is cut away so that about ¼ or ½ inch of lead projects. The lead can then be sharpened to a chisel edge by rubbing it against a bit of sand paper or a fine file. It should be ground to a chisel edge and the corners slightly rounded. In making the straight lines the chisel edge should be used by placing it against the T-square or triangle, and because of the chisel edge the lead will remain sharp much longer than if sharpened to a point. This chisel edge enables the draftsman to draw a fine line exactly through a given point. If the drawing is not to be inked, but is made for tracing or for rough usage in the shop, a softer pencil, 3H or 4H, may be used, as the lines will then be somewhat thicker and heavier. The lead for compasses may also be sharpened to a point although some draftsmen prefer to use a chisel edge in the compasses as well as for the pencil.

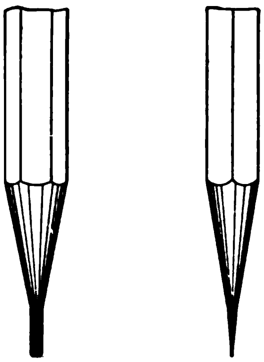


Fig. 1.

In using a very hard lead pencil, the chisel edge will make a deep depression in the paper if much pressure is put on the pencil. As this depression cannot be erased it is much better to press lightly on the pencil.

Erasers. In making drawings, but little erasing should be necessary. However, in case this is necessary, a soft rubber should be used. In erasing a line or letter, great care must be exercised or the surrounding work will also become erased. To prevent this, some draftsmen cut a slit about 3 inches long and ⅛ to ¼ inch wide in a card as shown in Fig. 2. The card is then placed over the work and the line erased without erasing the rest of the drawing. An erasing shield of a form similar to that shown in Fig. 3 is very convenient, especially in erasing letters. It is made of thin sheet metal and is clean and durable.

For cleaning drawings, a sponge rubber may be used. Bread crumbs are also used for this purpose. To clean the drawing scatter *dry* bread crumbs over it and rub them on the surface with the hand.

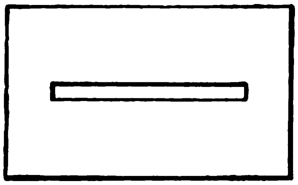


Fig. 2.

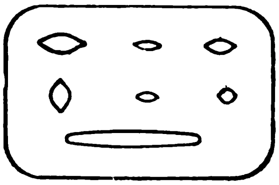


Fig. 3.

T-Square. The T-square consists of a thin straight edge called the blade, fastened to a head at right angles to it. It gets its name from the general shape. T-squares are made of various materials, wood being the most commonly used. Fig. 4 shows an ordinary form of T-square which is adapted to most work. In Fig. 5 is shown a T-square with edges made of ebony or mahogany, as these woods are much harder than pear wood or maple, which is generally used. The head is formed so as to fit against the left-hand edge of the drawing board, while the blade extends over the surface. It is desirable to have the blade of the T-square form a right angle with the head, so that the lines drawn with the T-square will be at right angles to the left-hand edge of the board. This, however, is not absolutely necessary, because the lines drawn with the T-square are always with reference to one edge of the

Fig. 4.

board only, and if this edge of the board is straight, the lines drawn with the T-square will be parallel to each other. The T-square should never be used except with the left-hand edge of the board, as it is almost impossible to find a drawing broad with the edges parallel or at right angles to each other.

The T-square with an adjustable head is frequently very convenient, as it is sometimes necessary to draw lines parallel to each other which are not at right angles to the left-hand edge of the board. This form of T-square is similar to the ordinary T-square already described, but the head is swiveled so that it may be clamped at any desired angle. The ordinary T-square as shown in Figs. 4 and 5 is, however, adapted to almost any class of drawing.

Fig. 5.

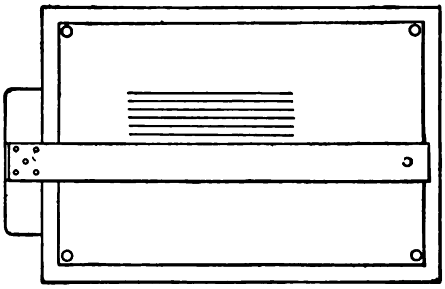


Fig. 6.

Fig. 6 shows the method of drawing parallel horizontal lines with the T-square. With the head of the T-square in contact with the left-hand edge of the board, the lines may be drawn by moving the T-square to the desired position. In using the T-square the upper edge should always be used for drawing as the two edges may not be exactly parallel and straight, and also it is more convenient to use this edge with the triangles. If it is necessary to use a straight edge for trimming drawings or cutting the paper from the board, the lower edge of the T-square should be used so that the upper edge may not be marred.

For accurate work it is absolutely necessary that the working edge of the T-square should be exactly straight. To test the straightness of the edge of the T-square, two T-squares may be placed together as shown in Fig. 7. This figure shows plainly that the edge of one of the T-squares is crooked. This fact, however, does not prove that either one is straight, and for this determination a third blade must be used and tried with the two given T-squares successively.

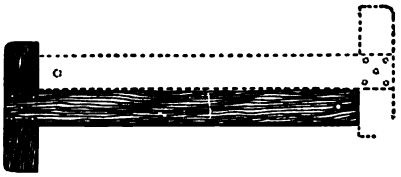
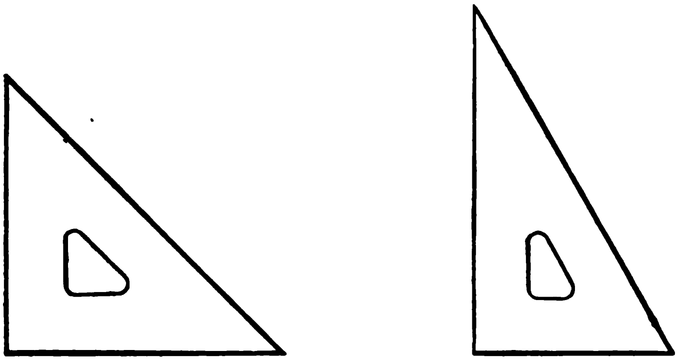


Fig. 7.

Triangles. Triangles are made of various substances such as wood, rubber, celluloid and steel. Wooden triangles are cheap but are likely to warp and get out of shape. The rubber triangles are frequently used, and are in general satisfactory. The transparent celluloid triangle is, however, extensively used on account of its transparency, which enables the draftsmen to see the work already done even when covered with the triangle. In using a rubber or celluloid triangle take care that it lies perfectly flat or is hung up when not in use; when allowed to lie on the drawing board with a pencil or an eraser under one corner it will become warped in a short time, especially if the room is hot or the sun happens to strike the triangle.


TRIANGLES.

Triangles are made in various sizes, and many draftsmen have several constantly on hand. A triangle from 6 to 8 inches on a side will be found convenient for most work, although there are many cases where a small triangle measuring about 4 inches on a side will be found useful. Two triangles are necessary for every draftsman, one having two angles of 45 degrees each and one a right angle; and the other having one angle of 60 degrees, one of 30 degrees and one of 90 degrees.

The value of the triangle depends upon the accuracy of the angles and the straightness of the edges. To test the accuracy of the right angle of a triangle, place the triangle with the lower edge resting on the edge of the T-square, as shown in Fig. 8. Now draw the line C D, which should be perpendicular to the edge of the T-square. The same triangle should then be placed in the position shown at B. If the right angle of the triangle is exactly 90 degrees the left-hand edge of the triangle should exactly coincide with the line C D.

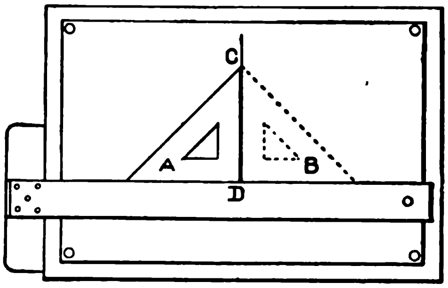


Fig. 8.

To test the accuracy of the 45-degree triangles, first test the right angle then place the triangle with the lower edge resting on the working edge of the T-square, and draw the line E F as shown in Fig. 9. Now without moving the T-square place the triangle so that the other 45-degree angle is in the position occupied by the first. If the two 45-degree angles coincide they are accurate.

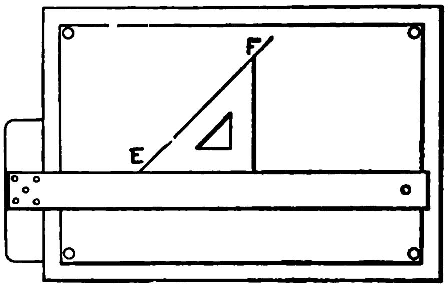
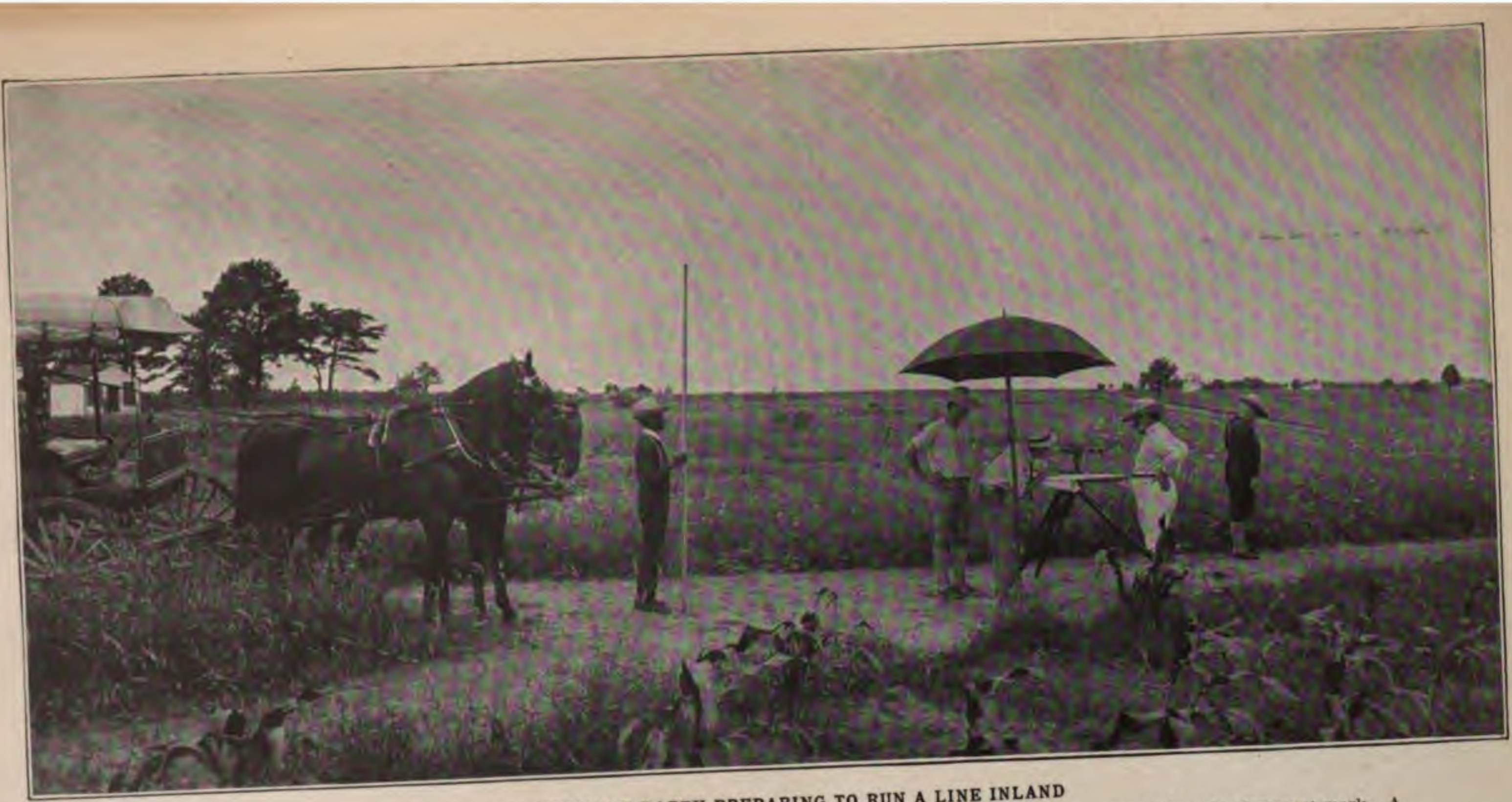


Fig. 9.

Triangles are very convenient in drawing lines at right angles to the T-square. The method of doing this is shown in Fig. 10. Triangles are also used in drawing lines at an angle with the horizontal, by placing them on the board as shown in Fig. 11. Suppose the line E F (Fig. 12) is drawn at any angle, and we wish to draw a line through the point P parallel to it



PLANE-TABLE PARTY PREPARING TO RUN A LINE INLAND

Such a surveying party usually consists of four to six men, with a team and wagon for inland work, or a launch and tender for coast work. A triangulation party has previously gone over the ground and located with great accuracy certain points marked by "signals." Using these points as bases to work from, the plane-table party, by means of the alidade, determines exactly the location and bearing of all important topographical features, charting them to scale upon the plane-table sheet directly from nature. From data thus obtained, the final charts are made.

First place one of the triangles as shown at A, having one edge coinciding with the given line. Now take the other triangle and place one of its edges in contact with the bottom edge of triangle A. Holding the triangle B firmly with the left hand the triangle A may be slipped along to the right or to the left until the edge of the triangle reaches the point P. The line M N may then be drawn along the edge of the triangle passing through the point P. In place of the triangle B any straight edge such as a T-square may be used.

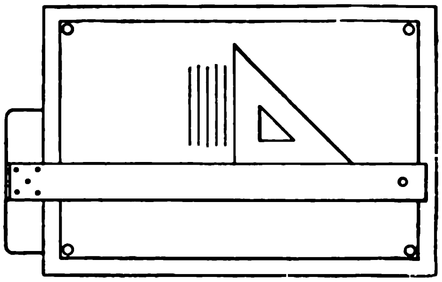


Fig. 10.

A line can be drawn perpendicular to another by means of the triangles as follows. Let E F (Fig. 13) be the given line, and suppose we wish to draw a line perpendicular to E F through the point D. Place the longest side of one of the triangles so that it coincides with the line E F, as the triangle is shown in position at A. Place the other triangle (or any straight edge) in the position of the triangle as shown at B, one edge resting against the edge of the triangle A. Then holding B with the left hand, place the triangle A in the position shown at C, so that the longest side passes through the point D. A line can then be drawn through the point D perpendicular to E F.

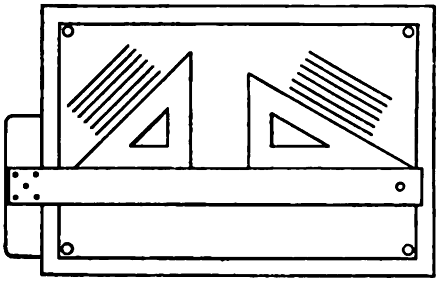


Fig. 11.

In previous figures we have seen how lines may be drawn making angles of 30, 45, 60 and 90 degrees with the horizontal. If it is desired to draw lines forming angles of 15 and 75 degrees the triangles may be placed as shown in Fig. 14.

In using the triangles and T-square almost any line may be drawn. Suppose we wish to draw a rectangle having one side horizontal. First place the T-square as shown in Fig. 15. By moving the T-square up or down, the sides A B and D C may be drawn, because they are horizontal and parallel. Now place one of the triangles resting on the T-square as shown at E, and having the left-hand edge passing through the point D. The vertical line D A may be drawn, and by sliding the triangle along the edge of the T-square to the position F the line B C may be drawn by using the same edge. These positions are shown dotted in Fig. 15.

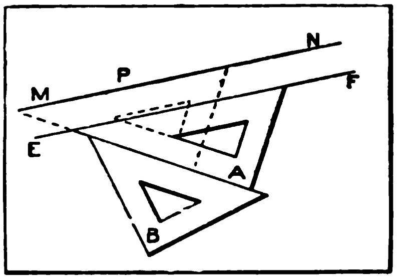


Fig. 12.

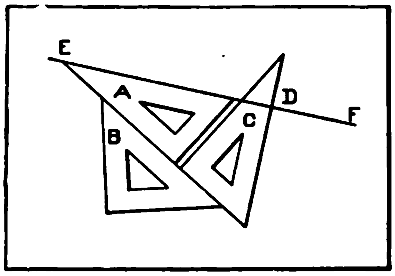


Fig. 13.

If the rectangle is to be placed in some other position on the drawing board, as shown in Fig. 16, place the 45-degree triangle F so that one edge is parallel to or coincides with the side D C. Now holding the triangle F in position place the triangle H so that its upper edge coincides with the lower edge of the triangle F. By holding H in position and sliding the triangle F along its upper edge, the sides A B and D C may be drawn. To draw the sides A D and B C the triangle should be used as shown at E.

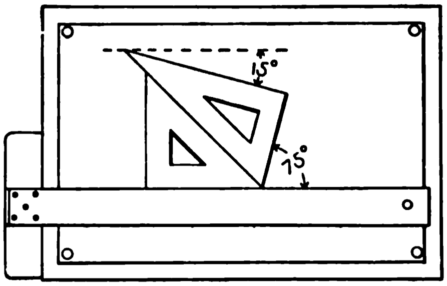


Fig. 14.

Compasses. Compasses are used for drawing circles and arcs of circles. They are made of various materials and in various sizes. The cheaper class of instruments are made of brass, but they are unsatisfactory on account of the odor and the tendency to tarnish The best material is German silver. It does not soil readily, it has no odor, and is easy to keep clean. Aluminum instruments possess the advantage of lightness, but on account of the soft metal they do not wear well.

The compasses are made in the form shown in Figs. 17 and 18. Pencil and pen points are provided, as shown in Fig. 17. Either pen or pencil may be inserted in one leg by means of a shank and socket. The other leg is fitted with a needle point which is placed at the center of the circle. In most instruments the needle point is separate, and is made of a piece of round steel wire having a square shoulder at one or both ends. Below this shoulder the needle point projects. The needle is made in this form so that the hole in the paper may be very minute.

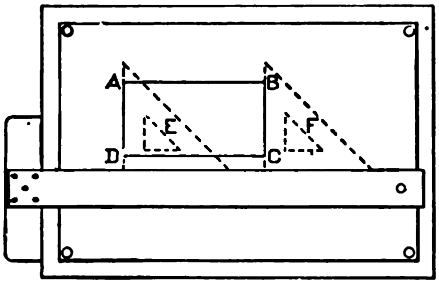


Fig. 15.

In some instruments lock nuts are used to hold the joint firmly in position. These lock nuts are thin discs of steel, with notches for using a wrench or forked key. Fig. 19 shows the detail of the joint of high grade instruments. Both legs are alike at the joint, and two pivoted screws are inserted in the yoke. This permits ample movement of the legs, and at the same time gives the proper stiffness. The flat surface of one of the legs is faced with steel, the other being of German silver, in order that the rubbing parts may be of different metals. Small set screws are used to prevent the pivoted screws from turning in the yoke. The contact surfaces of this joint are made circular to exclude dust and dirt and to prevent rusting of the steel face.

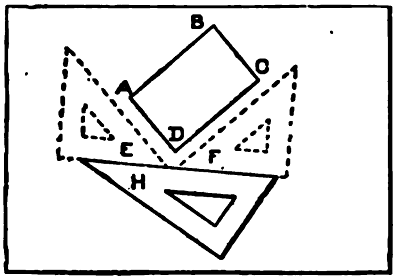


Fig. 16.

Figs. 20, 21 and 22 show the detail of the socket; in some instruments the shank and socket are pentagonal, as shown in Fig. 20. The shank enters the socket loosely, and is held in place by means of the screw. Unless used very carefully this arrangement is not durable because the sharp corners soon wear, and the pressure on the set screw is not sufficient to hold the shank firmly in place.

In Fig. 21 is shown another form of shank. This is round, having a flat top. A set screw is also used to hold this in position. A still better form of socket is shown in Fig. 22; the hole is made tapered and is circular. The shank fits accurately, and is held in perfect alignment by a small steel key. The clamping screw is placed upon the side, and keeps the two portions of the split socket together.

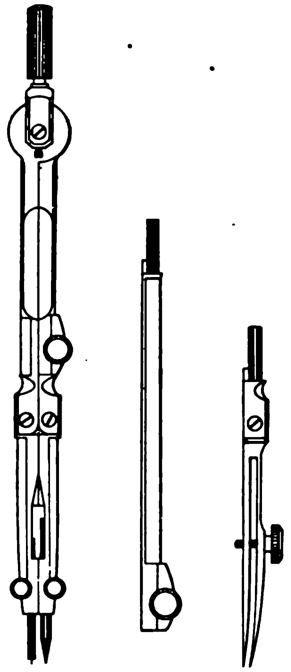


Fig. 17.

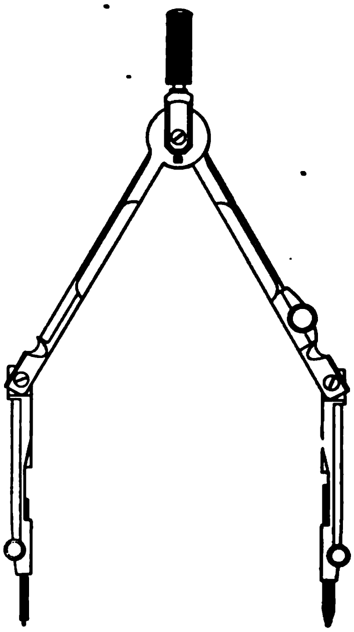


Fig. 18.

Figs. 17 and 18 show that both legs of the compasses are jointed in order that the lower part of the legs may be perpendicular to the paper while drawing circles. In this way the needle point makes but a small hole in the paper, and both nibs of the pen will press equally on the paper. In pencilling circles it is not as necessary that the pencil should be kept vertical; it is a good plan, however, to learn to use them in this way both in pencilling and inking. The compasses should be held loosely between the thumb and forefinger. If the needle point is sharp, as it should be, only a slight pressure will be required to keep it in place. While drawing the circle, incline the compasses slightly in the direction of revolution and press lightly on the pencil or pen.

In removing the pencil or pen, it should be pulled out straight. If bent from side to side the socket will become enlarged and the shank worn; this will render the instrument inaccurate. For drawing large circles the lengthening bar shown in Fig. 17 should be used. When using the lengthening bar the needle point should be steadied with one hand and the circle described with the other.

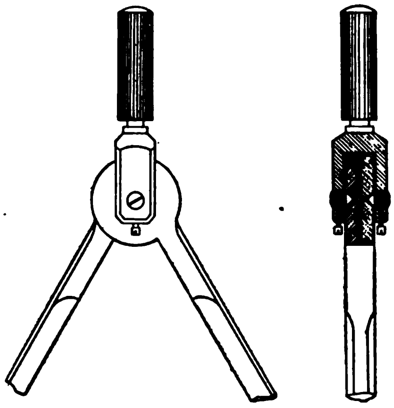


Fig. 19.

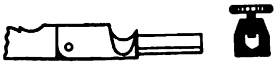


Fig. 20.

Fig. 21.

Dividers. Dividers, shown in Fig. 23, are made similar to the compasses. They are used for laying off distances on the drawing, either from scales or from other parts of the drawing. They may also be used for dividing a line into equal parts. When dividing a line into equal parts the dividers should be turned in the opposite direction each time, so that the moving point passes alternately to the right and to the left. The instrument can then be operated readily with one hand. The points of the dividers should be very sharp so that the holes made in the paper will be small. If large holes are made in the paper, and the distances between

Fig. 22.

the points are not exact, accurate spacing cannot be done Sometimes the compasses are furnished with steel divider points in addition to the pen and pencil points. The compasses may then be used either as dividers or as compasses. Many draftsmen use a *needle point* in place of dividers for making measurements from a scale. The eye end of a needle is first broken off and the needle then forced into a small handle made of a round piece of soft pine. This instrument is very convenient for indicating the intersection of lines and marking off distances.

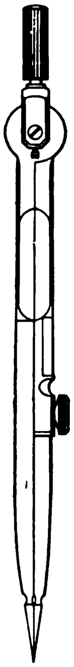


Fig. 23.

Bow Pen and Bow Pencil. Ordinary large compasses are too heavy to use in making small circles, fillets, etc. The leverage of the long leg is so great that it is very difficult to draw small circles accurately. For this reason the bow compasses shown in Figs. 24 and 25 should be used on all arcs and circles having a radius of less than three-quarters inch. The bow compasses are also convenient for duplicating small circles such as those which represent boiler tubes, bolt holes, etc., since there is no tendency to slip.

The needle point must be adjusted to the same length as the pen or pencil point if very small circles are to be drawn. The adjustment for altering the radius of the circle can be made by turning the nut. If the change in radius is considerable the points should be pressed together to remove the pressure from the nut which can then be turned in either direction with but little wear on the threads.

Fig. 26 shows another bow instrument which is frequently used in small work in place of the dividers. It has the advantage of retaining the adjustment.

Drawing Pen. For drawing straight lines and curves that are not arcs of circles, the line pen (sometimes called the ruling pen) is used. It consists of two blades of steel fastened to a handle as shown in Fig. 27. The distance between the pen points can be adjusted by the thumb screw, thus regulating the width of line to be drawn. The blades are given a slight curvature so that there will be a cavity for ink when the points are close together.

The pen may be filled by means of a common steel pen or with the quill which is provided with some liquid inks. The pen should not be dipped in the ink because it will then be necessary to wipe the outside of the blades before use. The ink should fill the pen to a height of about $\frac{1}{4}$ or $\frac{3}{8}$ inch; if too much ink is placed in the pen it is likely to drop out and spoil the drawing. Upon finishing the work the pen should be carefully wiped with chamois or a soft cloth, because most liquid inks corrode the steel.

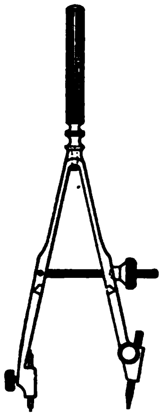


Fig. 24.

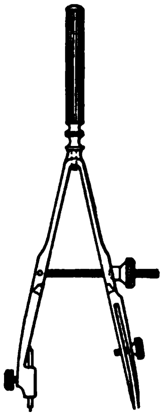


Fig. 25.

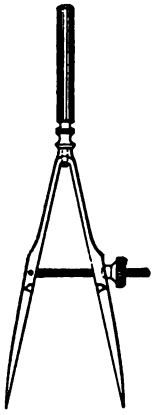


Fig. 26.

In using the pen, care should be taken that both blades bear equally on the paper. If the points do not bear equally the line will be ragged. If both points touch, and the pen is in good condition the line will be smooth. The pen is usually inclined slightly in the direction in which the line is drawn. The pen should *touch* the triangle or T-square which serve as guides, but it should not be pressed against them because the lines will then be uneven. The points of the pen should be close to the edge of the triangle or T-square, but should not touch it.

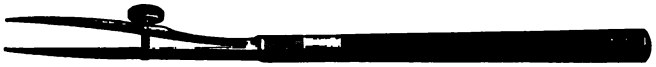


Fig. 27.

To Sharpen the Drawing Pen. After the pen has been used for some time the points become worn, and it is impossible to make smooth lines. This is especially true if rough paper is used. The pen can be put in proper condition by sharpening it. To do this take a small, flat, close-grained oil-stone. The blades should first be screwed together, and the points of the pen can be given the proper shape by drawing the pen back and forth over the stone changing the inclination so that the shape of the ends will be parabolic. This process dulls the points but gives them the proper shape, and makes them of the same length.

To sharpen the pen, separate the points slightly and rub one of them on the oil-stone. While doing this keep the pen at an angle of from 10 to 15 degrees with the face of the stone, and give it a slight twisting movement. This part of the operation requires great care as the shape of the ends must not be altered. After the pen point has become fairly sharp the other point should be ground in the same manner. All the grinding should be done on the *outside* of the blades. The burr should be removed from the inside of the blades by using a piece of leather or a piece of pine wood.

Ink should now be placed between the blades and the pen tried. The pen should make a smooth line whether fine or heavy, but if it does not the grinding must be continued and the pen tried frequently.

Ink. India ink is always used for drawing as it makes a permanent black line. It may be purchased in solid stick form or as a liquid. The liquid form is very convenient as much time is saved, and all the lines will be of the same color; the acid in the ink, however, corrodes steel and makes it necessary to keep the pen perfectly clean.

Some draftsmen prefer to use the India ink which comes in stick form. To prepare it for use, a little water should be placed in a saucer and one end of the stick placed in it. The ink is ground by giving it a twisting movement. When the water has become black and slightly thickened, it should be tried. A heavy line should be made on a sheet of paper and allowed to dry. If the line has a grayish appearance, more grinding is necessary. After the ink is thick enough to make a good black line, the grinding should cease, because very thick ink will not flow freely from the pen. If, however, the ink has become too thick, it may be diluted with water. After using, the stick should be wiped dry to prevent crumbling. It is well to grind the ink in small quantities as it does not dissolve readily if it has once become dry. If the ink is kept covered it will keep for two or three days.

Scales. Scales are used for obtaining the various measurements on drawings. They are made in several forms, the most convenient being the flat with beveled edges and the triangular. The scale is usually a little over 12 inches long and is graduated for a distance of 12 inches. The triangular scale shown in Fig. 28 has six surfaces for graduations, thus allowing many graduations on the same scale.

The graduations on the scales are arranged so that the drawings may be made in any proportion to the actual size. For mechanical work, the common divisions are multiples of two. Thus we make drawings full size, half size, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$, $\frac{1}{64}$, etc. If a drawing is $\frac{1}{4}$ size, 3 inches equals 1 foot, hence 3 inches is divided into 12 equal parts and each division represents one inch. If the smallest division on a scale represents $\frac{1}{16}$ inch, the scale is said to read to $\frac{1}{16}$ inch.

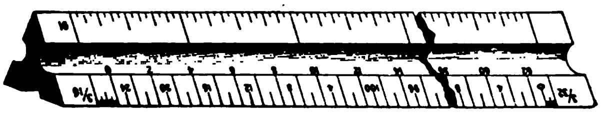


Fig. 28.

Scales are often divided into $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{30}$, $\frac{1}{40}$, etc., for architects, civil engineers, and for measuring on indicator cards.

The scale should never be used for drawing lines in place of triangles or T-square.

Protractor. The protractor is an instrument used for laying off and measuring angles. It is made of steel, brass, horn and paper. If made of metal the central portion is cut out as shown in Fig. 29, so that the draftsman can see the drawing. The outer edge is divided into degrees and tenths of degrees. Sometimes the graduations are very fine. In using a protractor a very sharp hard pencil should be used so that the lines will be fine and accurate.

The protractor should be placed so that the given line (produced if necessary) coincides with the two O marks. The center of the circle being placed at the point through which the desired line is to be drawn. The division can then be marked with the pencil point or needle point.

Irregular Curve. One of the conveniences of a draftsman's outfit is the French or irregular curve. It is made of wood, hard rubber or celluloid, the last named material being the best. It is made in various shapes, two of the most common being shown in Fig. 30. This instrument is used for drawing curves other than arcs of circles, and both pencil and line pen can be used.

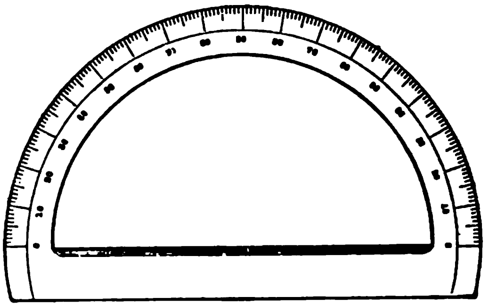


Fig. 29.

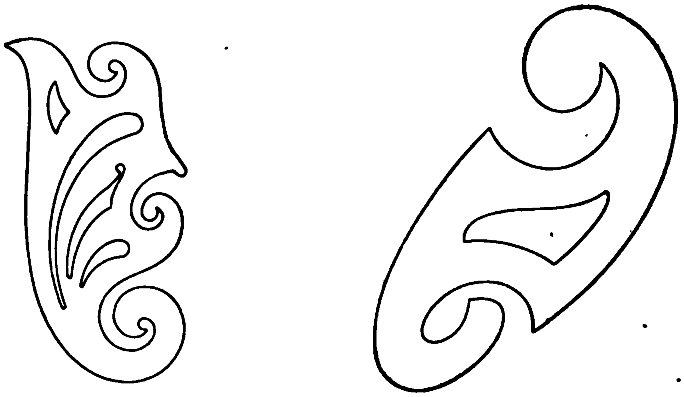


Fig. 30.

To draw the curve, a series of points is first located and then the curve drawn passing through them by using the part of the irregular curve that passes through several of them The curve is shifted for this work from one position to another. It frequently facilitates the work and improves its appearance to draw a free hand pencil curve through the points and then use the irregular curve, taking care that it always fits at least *three* points.

In inking the curve, the blades of the pen must be kept tangent to the curve, thus necessitating a continual change of direction.

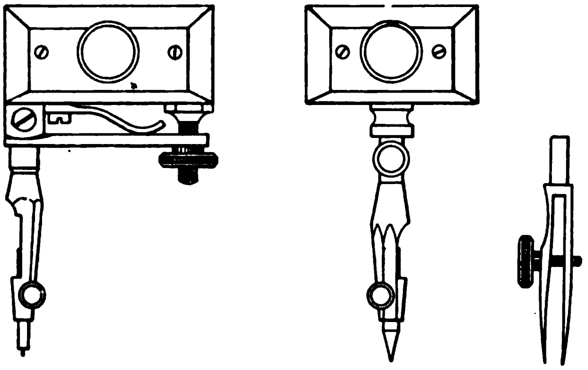


Fig. 31.

Beam Compasses. The ordinary compasses are not large enough to draw circles having a diameter greater than about 8 or 10 inches. A convenient instrument for larger circles is found in the beam compasses shown in Fig. 31. The two parts called channels carrying the pen or pencil and the needle point are clamped to a wooden beam; the distance between them being equal to the radius of the circle. Accurate adjustment is obtained by means of a thumb nut underneath one of the channel pieces.

LETTERING.

No mechanical drawing is finished unless all headings, titles and dimensions are lettered in plain, neat type. Many drawings are accurate, well-planned and finely executed but do not present a good appearance because the draftsman did not think it worth while to letter well. Lettering requires time and patience; and if one wishes to letter rapidly and well he must practice.

Usually a beginner cannot letter well, and in order to produce a satisfactory result, considerable practice is necessary. Many think it a good plan to practice lettering before commencing a drawing. A good writer does not always letter well; a poor writer need not be discouraged and think he can never learn to make a neatly lettered drawing.

In making large letters for titles and headings it is often necessary to use drawing instruments and mechanical aids. The small letters, such as those used for dimensions, names of materials, dates, etc., **should be made free hand.**

There are many styles of letters used by draftsmen. For titles, large Roman capitals are frequently used, although Gothic and block letters also look well and are much easier to make.

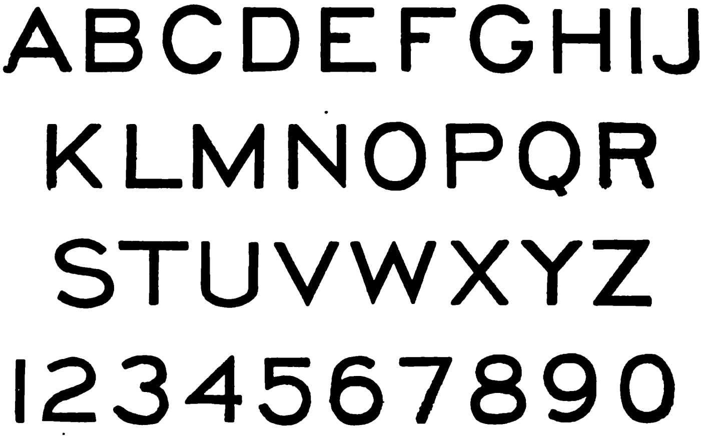


Fig. 32.

Almost any neat letter free from ornamentation is acceptable in the regular practice of drafting. Fig. 32 shows the alphabet of vertical Gothic capitals. These letters are neat, plain and easily made. The inclined or italicized Gothic type is shown in Fig. 33. This style is also easy to construct, and possesses the advantage that a slight difference in inclination is not apparent. If the vertical lines of the vertical letters incline slightly the inaccuracy is very noticeable.

The curves of the inclined Gothic letters such as those in the *B*, *C*, *G*, *J*, etc., are somewhat difficult to make free hand, especially if the letters are about one-half inch high. In the alphabet shown in Fig. 34, the letters are made almost wholly of straight lines, the corners only being curved. These letters are very easy to make and are clear cut.

The first few plates of this work will require no titles; the only lettering being the student's name, together with the date and plate number. Later, the student will take up the subject of lettering again in order to letter titles and headings for drawings showing the details of machines. For the present, however, inclined Gothic capitals will be used.

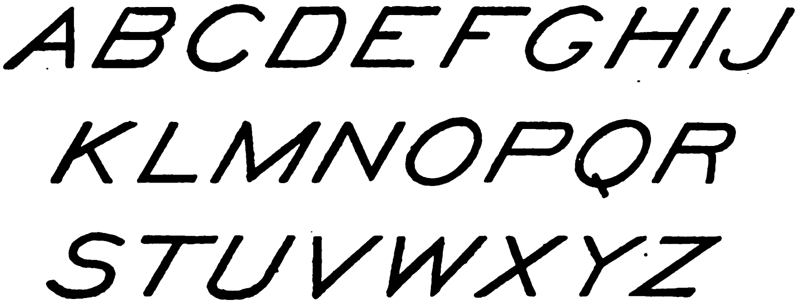


Fig. 33.

To make the inclined Gothic letters, first draw two parallel lines having the distance between them equal to the desired height of the letters. If two sizes of letters are to be used, the smaller should be about two-thirds as high as the larger. For the letters to be used on the first plates, draw two parallel lines $\frac{5}{32}$ inch apart. This is the height for the letters of the date, name, also the plate number, and should be used on all plates throughout this work, unless other directions are given.

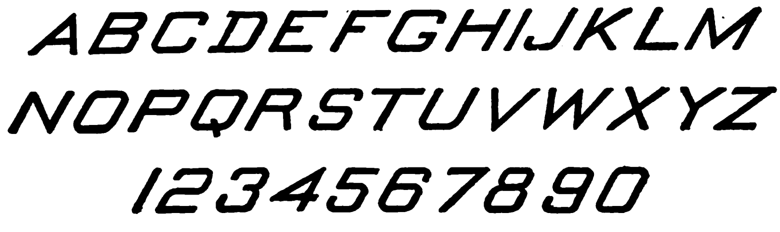


Fig. 34.

In constructing the letters, they should extend fully to these lines, both at the top and bottom. They should not fall short of the guide lines nor extend beyond them. As these letters are inclined they will look better if the inclination is the same for all. As an aid to the beginner, he can draw light pencil lines, about ¼ inch apart, forming the proper angle with the parallel lines already drawn. The inclination is often made about 70 degrees; but as a 60-degree triangle is at hand, it may be used. To draw these lines place the 60-degree triangle on the T-square as shown in Fig. 36. In making these letters the 60-degree lines will be found a great aid as a large proportion of the back or side lines have this inclination.

Capital letters such as *E*, *F*, *P*, *T*, *Z*, etc., should have the top lines coincide with the upper horizontal guide line. The bottom lines of such letters as *D*, *E*, *L*, *Z*, etc., should coincide with the lower horizontal guide line. If these lines do not coincide with the guide lines the words will look uneven. Letters, of which *C*, *G*, *O*, and *Q*, are types, can be formed of curved lines or of straight lines. If made of curved lines, they should have a little greater height than the guide lines to prevent their appearing smaller than the other letters. In this work they can be made of straight lines with rounded corners as they are easily constructed and the student can make all letters of the same height.

To construct the letter *A*, draw a line at an angle of 60 degrees to the horizontal and use it as a center line. Then from the intersection of this line and the upper horizontal line drop a vertical line to the lower guide line. Draw another line from the vertex meeting the lower guide line at the same distance from the center line. The cross line of the *A* should be a little below the center. The *V* is an inverted *A* without the cross line. For the letter *M*, the side lines should be parallel and about the same distance apart as are the horizontal lines. The side lines of the *W* are *not* parallel but are farther apart at the top. The *J* is not quite as wide as such letters as *H*, *E*, *N*, *R*, etc. To make a *Y*, draw the center line 60 degrees to the horizontal; the diverging lines are similar to those of the *V* but are shorter and form a larger angle. The diverging lines should meet the center line a little below the middle.

The lower-case letters are shown in Fig. 35. In such letters as *m*, *n*, *r*, etc., make the corners sharp and not rounding. The letters *a*, *b*, *c*, *e*, *g*, *o*, *p*, *q*, should be full and rounding. The figures (see Fig. 32) are made as in writing — except the *4*, *6*, *8* and *9*.

The Roman numerals are made of straight lines as they are largely made up of *I*, *V* and *X*.

At first the copy should be followed closely and the letters drawn in pencil. For a time, the inclined guide lines may be used,

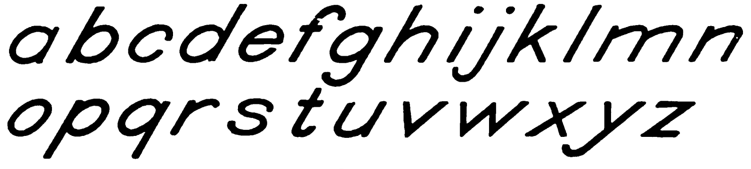


Fig. 35.

but after the proper inclination becomes firmly fixed in mind they should be abandoned. The horizontal lines are used at all times by most draftsmen. After the student has had considerable practice, he can construct the letters in ink without first using the pencil. Later in the work, when the student has become proficient in the simple inclined Gothic capitals, the vertical, block and Roman alphabets should be studied.

PLATES.

To lay out a sheet of paper for the plates of this work, the sheet, A B G F, (Fig. 36) is placed on the drawing board 2 or 3 inches from the left-hand edge which is called the *working edge*. If placed near the left-hand edge, the T-square and triangles can be used with greater firmness and the horizontal lines drawn with the T-square will be more accurate. In placing the paper on the board, always true it up according to the long edge of the sheet. First fasten the paper to the board with thumb tacks, using at least 4 — one at each corner. If the paper has a tendency to curl it is better to use 6 or 8 tacks, placing them as shown in Fig. 36. Thumb tacks are commonly used; but many draftsmen prefer one-ounce tacks as they offer less obstruction to the T-square and triangles.

After the paper is fastened in position, find the center of the

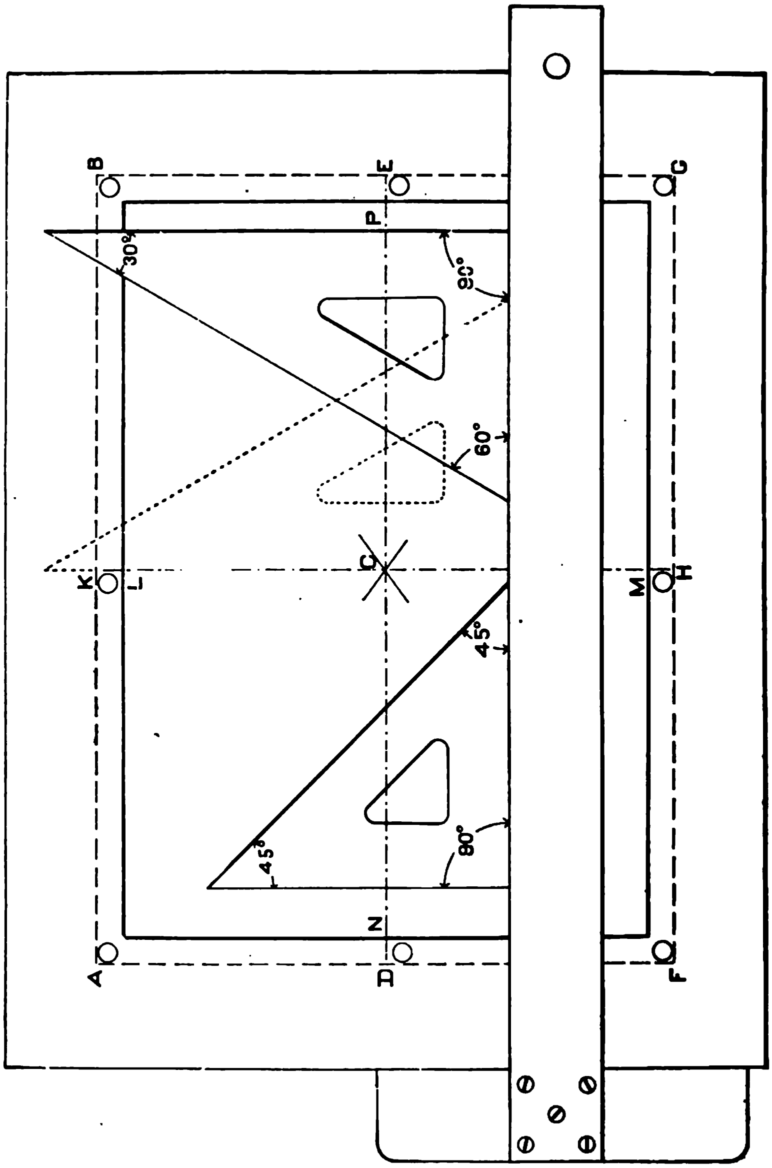


Fig. 36.

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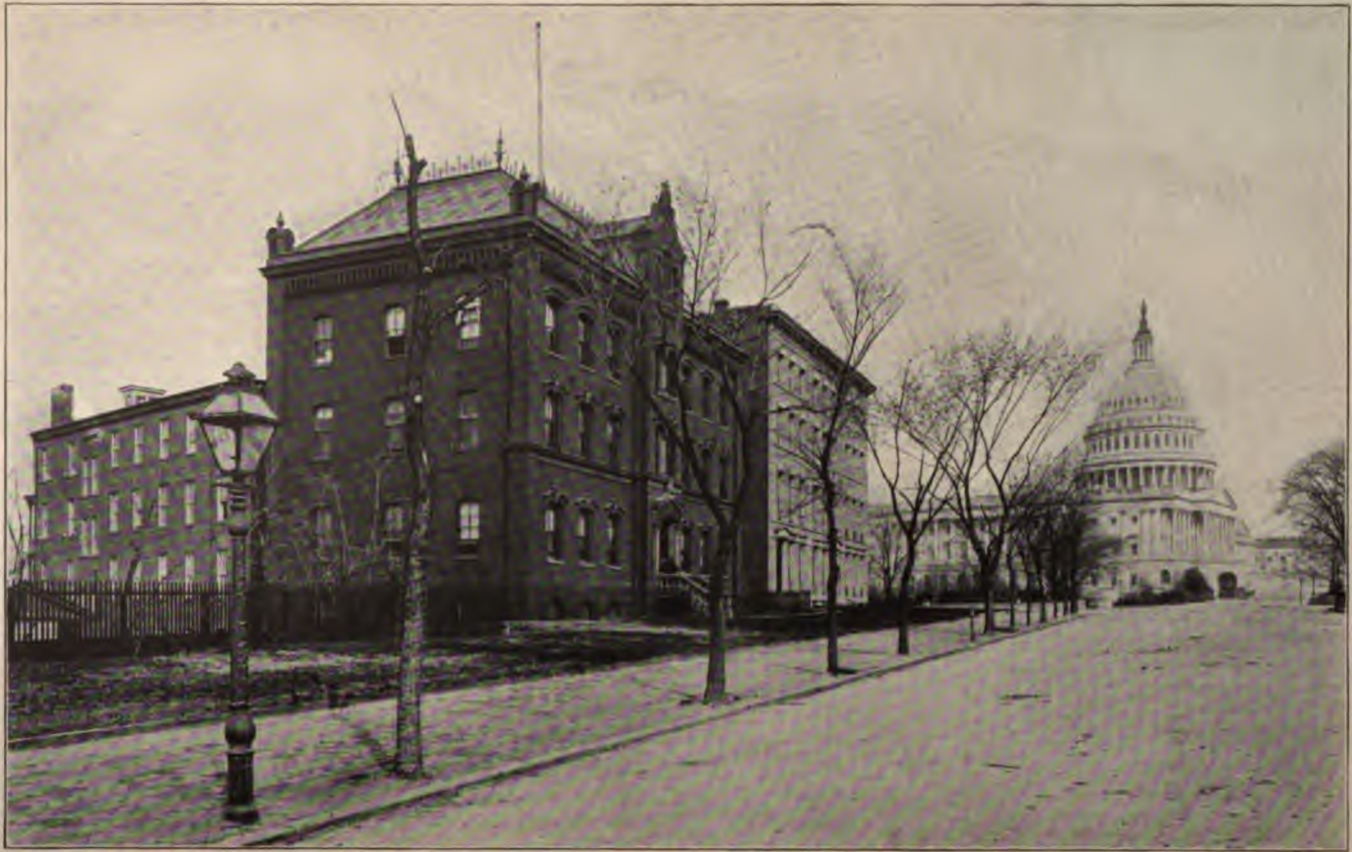

BUILDINGS OF THE U. S. COAST AND GEODETIC SURVEY, WASHINGTON, D. C.

The three Survey buildings here shown lie to the south of the Capitol, which appears in the background. Here are made the Government charts, which are invaluable aids to commerce and navigation. The site of the new office building of the U. S. Senate is across the street (to the right or east) from the Survey.

sheet by placing the T-square so that its upper edge coincides with the diagonal corners A and G and then with the corners F and B, drawing short pencil lines intersecting at C. Now place the T-square so that its upper edge coincides with the point C and draw the dot and dash line D E. With the T-square and one of the triangles (shown dotted) in the position shown in Fig. 36, draw the dot and dash line H C K. In case the drawing board is large enough, the line C H can be drawn by moving the T-square until it is entirely off the drawing. If the board is small, produce (extend) the line K C to H by means of the T-square or edge of a triangle. In this work always move the pencil from the left to the right or from the bottom upward; never (except for some particular purpose) in the opposite direction.

After the center lines are drawn measure off 5 inches above and below the point C on the line H C K. These points L and M may be indicated by a light pencil mark or by a *slight* puncture of one of the points of the dividers. Now place the T-square against the left-hand edge of the board and draw horizontal pencil lines through L and M.

Measure off 7 inches to the left and right of C on the center line D C E and draw pencil lines through these points (N and P) perpendicular to D E. We now have a rectangle 10 inches by 14 inches, in which all the exercises and figures are to be drawn. The lettering of the student's name and address, date, and plate number are to be placed *outside* of this rectangle in the ½-inch margin. In all cases lay out the plates in this manner and keep the center lines D E and K H as a basis for the various figures. The border line is to be inked with a heavy line when the drawing is inked.

Pencilling. In laying out plates, all work is first done in pencil and afterward inked or traced on tracing cloth. The first few plates of this course are to be done in pencil and then inked; later the subject of tracing and the process of making blue prints will be taken up. Every beginner should practice with his instruments until he can use them with accuracy and skill, and until he understands thoroughly what instrument should be used for making a given line. To aid the beginner in this work, the first three plates of this course are designed to give the student practice · they do not involve any problems and none of the work is difficult. The student is strongly advised to draw these plates two or three times before making the one to be sent to us for correction. Diligent practice is necessary at first; especially on *PLATE I* as it involves an exercise in lettering.

PLATE I.

Pencilling. To draw *PLATE I*, take a sheet of drawing paper at least 11 inches by 15 inches and fasten it to the drawing board as already explained. Find the center of the sheet and draw fine pencil lines to represent the lines D E and H K of Fig. 36. Also draw the border lines L, M, N and P.

Now measure $\frac{3}{8}$ inch above and below the horizontal center line and, with the T-square, draw lines through these points. These lines will form the lower lines D C of *Figs. 1* and *2* and the top lines A B of *Figs. 3* and *4*. Measure $\frac{3}{8}$ inch to the right and left of the vertical center line; and through these points, draw lines parallel to the center line. These lines should be drawn by placing the triangle on the T-square as shown in Fig. 36. The lines thus drawn, form the sides B C of *Figs. 1* and *3* and the sides A D of *Figs. 2* and *4*. Next draw the line A B A B with the T-square, $4\frac{5}{8}$ inches above the horizontal center line. This line forms the top lines of *Figs. 1* and *2*. Now draw the line D C D C $4\frac{5}{8}$ inches below the horizontal center line. The rectangles of the four figures are completed by drawing vertical lines $6\frac{5}{8}$ inches from the vertical center line. We now have four rectangles each $6\frac{1}{4}$ inches long and $4\frac{1}{4}$ inches wide.

Fig. 1 is an exercise with the line pen and T-square. Divide the line A D into divisions each $\frac{1}{4}$ inch long, making a fine pencil point or *slight* puncture at each division such as E, F, G, H, I, etc. Now place the T-square with the head at the left-hand edge of the drawing board and through these points draw light pencil lines extending to the line B C. In drawing these lines be careful to have the pencil point pass *exactly* through the division marks so that the lines will be the same distance apart. Start each line in the line A D and do not fall short of the line B C or run over it. Accuracy and neatness in pencilling insure an accurate drawing. Some beginners think that they can correct inaccuracies while

PLATE I

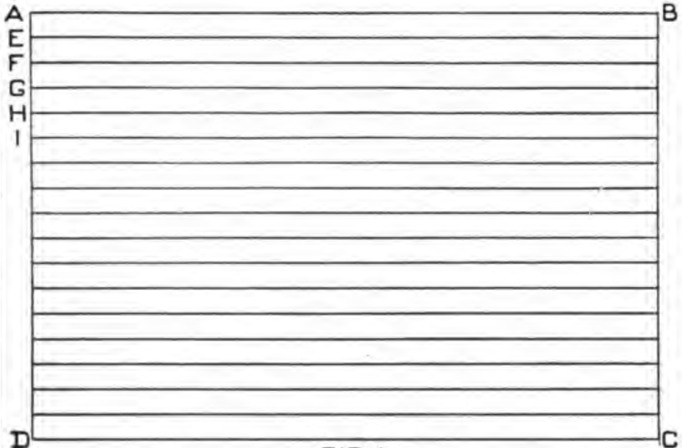

FIG. 1

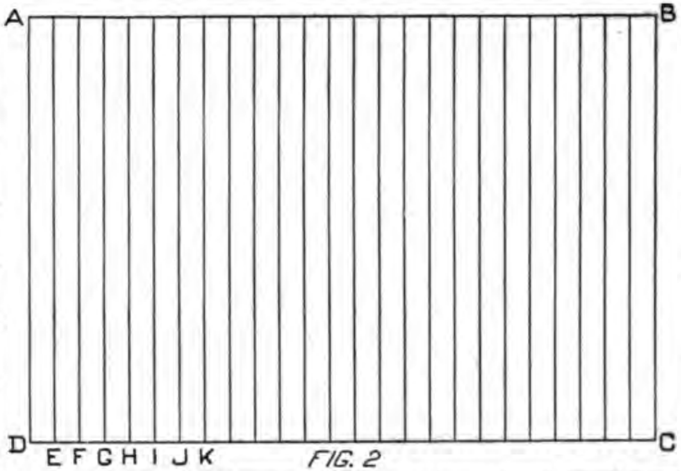

FIG. 2

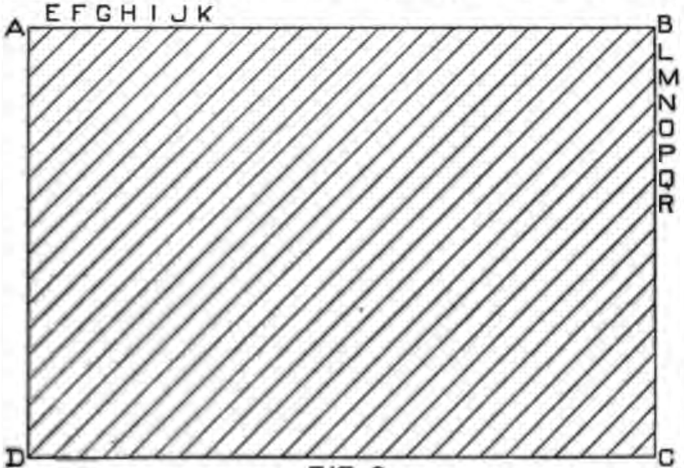

FIG. 3

A B

LETTERING

THE SUBJECT OF LETTERING IS OF GREAT IMPORTANCE TO THE MECHANICAL DRAUGHTSMAN. MANY WELL EXECUTED DRAWINGS HAVE BEEN DISFIGURED BY POOR LETTERING.

Proficiency can be acquired only by practice. Practice lettering. Practice.

ABCDEFGHIJKLMNOPQRSTUVWXYZ

abcdefghijklmnopqrstuvwxyz

1234567890

I II III IV V VI VII VIII IX X

D C

FIG. 4

inking; but experience soon teaches them that they cannot do so.

Fig. 2 is an exercise with the line pen, T-square and triangle. First divide the lower line D C of the rectangle into divisions each ¼ inch long and mark the points E, F, G, H, I, J, K, etc., as in *Fig. 1*. Place the T-square with the head at the left-hand edge of the drawing board and the upper edge in about the position shown in Fig. 36. Place either triangle with one edge on the upper edge of the T-square and the 90-degree angle at the left. Now draw fine pencil lines from the line D C to the line A B passing through the points E, F, G, H, I, J, K, etc. To do this keep the T-square rigid and slide the triangle toward the right, being careful to have the edge coincide with the division marks in succession.

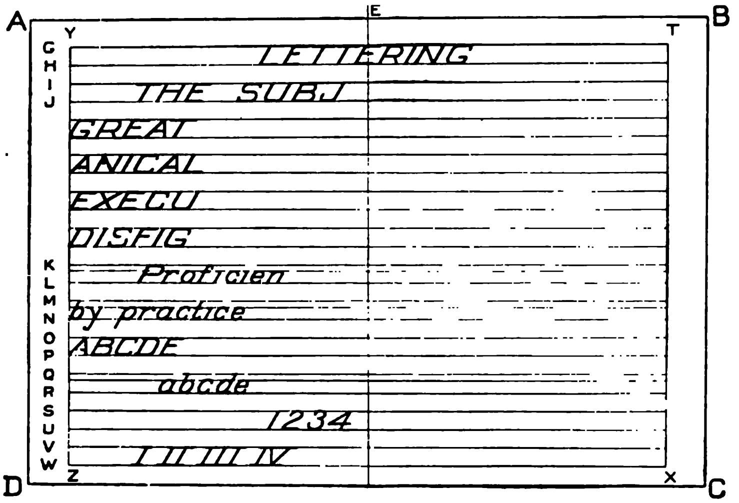

Fig. 37.

Fig. 3 is an exercise with the line pen, T-square and 45-degree triangle. First lay off the distances A E, E F, F G, G H, H I, I J, J K, etc., each ¼ inch long. Then lay off the distances B L, L M, M N, N O, O P, P Q, Q R, etc., also ¼ inch long. Place the T-square so that the upper edge will be below the line D C of *Fig. 3*. With the 45-degree triangle draw lines from A D and D C to the points E, F, G, H, I, J, K, etc., as far as the point B. Now draw lines from D C to the points L, M, N, O, P, Q, R, etc., as far as the point C. In drawing these lines move the pencil away from the body, that is, from A D to A B and from D C to B C.

Fig. 4 is an exercise in free-hand lettering. The finished exercise, with all guide lines erased, should have the appearance shown in *Fig. 4* of *PLATE I.* The guide lines are drawn as shown in Fig. 87. First draw the center line E F and light pencil lines Y Z and T X, $\frac{3}{8}$ inch from the border lines. Now, with the T-square, draw the line G, $\frac{1}{4}$ inch from the top line and the line H, $\frac{5}{32}$ inch below G. The word "*LETTERING*" is to be placed between these two lines. Draw the line I, $\frac{3}{16}$ inch below H. The lines I, J, etc., to K are all $\frac{5}{32}$ inch apart.

We now practice the lower-case letters. Draw the line L, $\frac{3}{16}$ inch below K and a light line $\frac{1}{8}$ inch above L to limit the height of the small letters. The space between L and M is $\frac{5}{32}$ inch. The lines M and N are drawn in the same manner as K and L. The space between N and O should be $\frac{1}{4}$ inch. The line P is drawn $\frac{5}{32}$ inch below O. Q is also $\frac{5}{32}$ inch below P. The lines Q and R are drawn $\frac{3}{16}$ inch apart as are M and N. The remainder of the lines S, U, V and W are drawn $\frac{5}{32}$ inch apart.

The center line is a great aid in centering the word "*LETTERING*," the alphabets, numerals, etc. The words "*THE*" and "*Proficiency*" should be indented about $\frac{3}{8}$ inch as they are the first words of paragraphs. To draw the guide lines, mark off distances of $\frac{1}{4}$ inch on any line such as J and with the 60-degree triangle draw light pencil lines cutting the parallel lines. The letters should be sketched in pencil, the ordinary letters such as E, F, H, N, R, etc. being made of a width equal to about $\frac{3}{4}$ the height. Letters like A, M and W are wider. The space between the letters depends upon the draftsman's taste but the beginner should remember that letters next to an A or an L should be placed near them and that greater space should be left on each side of an I or between letters whose sides are parallel; for instance there should be more space between an N and E than between an E and H. On account of the space above the lower line of the L, a letter following an L should be close to it. If a T follows a T or the letter L follows an L they should be placed near together. In all lettering the letters should be placed so that the general effect is pleasing. After the four figures are completed, the lettering for name, address and date should be pencilled. With the T-square draw a pencil line $\frac{5}{32}$ inch above the top border line at the right-hand end. This line should be about 3 inches long. At a distance of $\frac{5}{32}$ inch above this line draw another line of about the same length. These are the guide lines for the word *PLATE I.* The letters should be pencilled free hand and the student may use the 60-degree guide lines if he desires.

The guide lines of the date, name and address are similarly drawn in the lower margin. The date of completing the drawing should be placed under *Fig. 3* and the name and address at the right under *Fig. 4*. The street address is unnecessary. It is a good plan to draw lines $\frac{5}{32}$ inch apart on a separate sheet of paper and pencil the letters in order to know just how much space each word will require. The insertion of the words "*Fig. 1,*" "*Fig. 2,*" etc., is optional with the student. He may leave them out if he desires; but we would advise him to do this extra lettering for the practice and for convenience in reference. First draw with the T-square two parallel line $\frac{5}{32}$ inch apart under each exercise; the lower line being $\frac{1}{16}$ inch above the horizontal center line or above the lower border line.

Inking. After all of the pencilling of *PLATE I* has been completed the exercises should be inked. The pen should first be examined to make sure that the nibs are clean, of the same length and come together evenly. To fill the pen with ink use an ordinary steel pen or the quill in the bottle, if Higgin's Ink is used. Dip the quill or pen into the bottle and then inside between the nibs of the line pen. The ink will readily flow from the quill into the space between the nibs as soon as it is brought in contact. Do not fill the pen too full, if the ink fills about $\frac{1}{4}$ the distance to the adjusting screw it usually will be sufficient. If the filling has been carefully done it will not be necessary to wipe the outsides of the blades. However, any ink on the outside should be wiped off with a soft cloth or a piece of chamois.

The pen should now be tried on a separate piece of paper in order that the width of the line may be adjusted. In the first work where no shading is done, a firm distinct line should be used. The beginner should avoid the extremes; a very light line makes the drawing have a weak, indistinct appearance, and very heavy lines detract from the artistic appearance.and make the drawing appear heavy.

In case the ink does not flow freely, wet the finger and touch it to the end of the pen. If it then fails to flow, draw a slip of thin paper between the nibs (thus removing the dried ink) or clean thoroughly and fill. Never lay the pen aside without cleaning.

In ruling with the line pen it should be held firmly in the right hand almost perpendicular to the paper. If grasped too firmly the width of the line may be varied and the draftsman soon becomes fatigued. The pen is usually held so that the adjusting screw is away from the T-square, triangles, etc. Many draftsmen incline the pen slightly in the direction in which it is moving.

To ink *Fig. 1*, place the T-square with the head at the working edge as in pencilling. First ink all of the horizontal lines moving the T-square from A to D. In drawing these lines considerable care is necessary; both nibs should touch the paper and the pressure should be uniform. Have sufficient ink in the pen to finish the line as it is difficult for a beginner to stop in the middle of the line and after refilling the pen make a smooth continuous line. While inking the lines A, E, F, G, H, I, etc., greater care should be taken in starting and stopping than while pencilling. Each line should start *exactly* in the pencil line A D and stop in the line B C. The lines A D and B C are inked, using the triangle and T-square.

Fig. 2 is inked in the same manner as it was pencilled; the lines being drawn, sliding the triangle along the T-square in the successive positions.

In inking *Fig. 3*, the same care is necessary as with the preceding, and after the oblique lines are inked the border lines are finished. In *Fig. 4* the border lines should be inked in first and then the border lines of the plate. The border lines should be quite heavy as they give the plate a better appearance. The intersections should be accurate, as any running over necessitates erasing.

The line pen may now be cleaned and laid aside. It can be

PLATE II

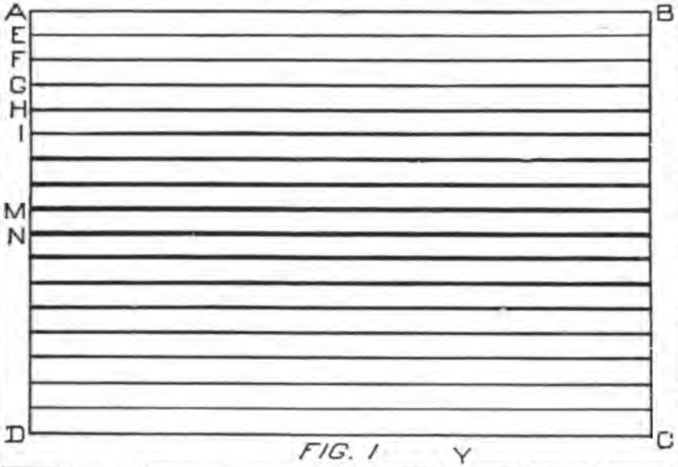

FIG. 1

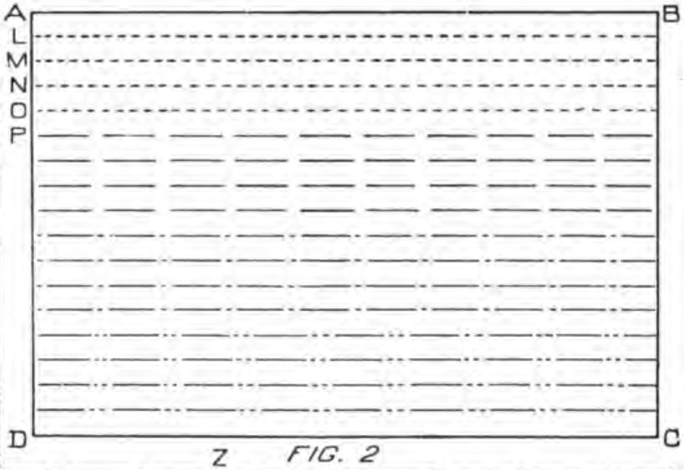

FIG. 2

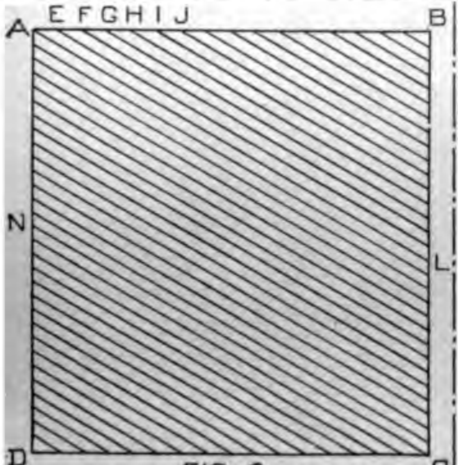

FIG. 3

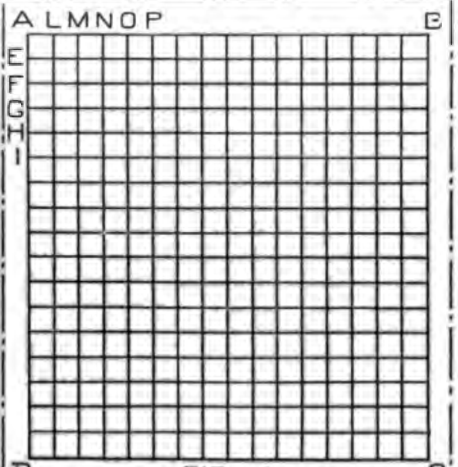

FIG. 4

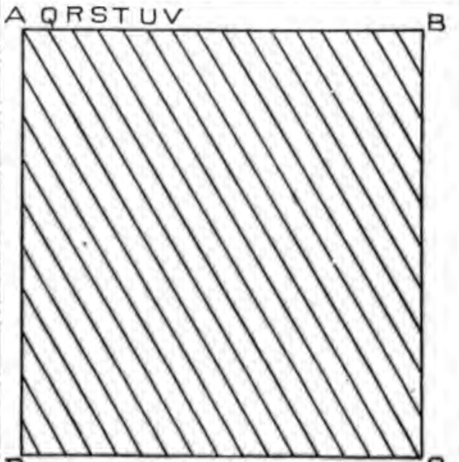

FIG. 5

cleaned by drawing a strip of blotting paper between the nibs or by means of a piece of cloth or chamois. The lettering should be done free-hand using a steel pen. If the pen is very fine, accurate work may be done but the pen is likely to catch in the paper, especially if the paper is rough. A coarser pen will make broader lines but is on the whole preferable. Gillott's 404 is as fine a pen as should be used. After inking *Fig. 4*, the plate number, date and name should be inked, also free-hand. After inking the words "*Fig. 1*," "*Fig. 2*," etc., all pencil lines should be erased. **In the finished drawing there should be no center lines, construction lines or letters other than those in the name, date, etc.**

The sheet should be cut to a size of 11 inches by 15 inches, the dash line outside the border line of *PLATE I* indicating the edge.

PLATE II.

Pencilling. The drawing paper used for *PLATE II* should be laid out as described with *PLATE I*, that is, the border lines, center line and rectangles for *Figs. 1* and *2*. To lay out *Figs. 3*, *4* and *5* proceed as follows: Draw a line with the T-square parallel to the horizontal center line and ⅜ inch below it. Also draw another similar line 4⅝ below the center line. The two lines will form the top and bottom of *Figs. 3*, *4* and *5*. Now measure off 2¼ inches on either side of the center on the horizontal center line and call the points Y and Z. On either side of Y and Z and at a distance of ¼ inch draw vertical parallel lines. Now draw a vertical line A D, 4¼ inches from the line Y and a vertical line B C 4¼ inches from the line Z. We now have three rectangles each 4 inches broad and 4¼ inches high. *Figs. 1* and *2* are pencilled in exactly the same way as was *Fig. 1* of *PLATE I*, that is, horizontal lines are drawn ¼ inch apart.

Fig. 3 is an exercise to show the use of a 60-degree triangle with a T-square. Lay off the distances A E, E F, F G, G H, etc. to B each ¼ inch. With the 60 degree triangle resting on the upper edge of the T-square, draw lines through these points, E, F, G, H, I, J, etc., forming an angle of 30 degrees with the horizontal. The last line drawn will be A L. In drawing these lines move the pencil from A B to B C. Now find the distance between the lines on the vertical B L and mark off these distances on the line B C commencing at L. Continue the lines from A L to N C. Commencing at N mark off distances on A D equal to those on B C and finish drawing the oblique lines.

Fig. 4 is an exercise for intersection. Lay off distances of $\frac{1}{4}$ inch on A B and A D. With the T-square draw fine pencil lines through the points E, F, G, H, I, etc., and with the T-square and triangle draw vertical lines through the points L, M, N, O, P, etc. In drawing this figure draw every line exactly through the points indicated as the symmetrical appearance of the small squares can be attained only by accurate pencilling.

The oblique lines in *Fig. 5* form an angle of 60 degrees with the horizontal. As in *Figs. 3* and *4* mark off the line A B in divisions of $\frac{1}{4}$ inch and draw with the T-square and 60-degree triangle the oblique lines through these points of division moving the pencil from A B to B C. The last line thus drawn will be A L. Now mark off distances of $\frac{1}{4}$ inch on C D beginning at L. The lines may now be finished.

Inking. *Fig. 1* is designed to give the beginner practice in drawing lines of varying widths. The line E is first drawn. This line should be rather fine but should be clear and distinct. The line F should be a little wider than E; the greater width being obtained by turning the adjusting screw from one-quarter to one-half a turn. The lines G, H, I, etc., are drawn; each successive line having greater width. M and N should be the same and quite heavy. From N to D the lines should *decrease* in width. To complete the inking of *Fig. 1*, draw the border lines. These lines should have about the same width as those in ***PLATE I.***

In *Fig. 2* the first four lines should be dotted. The dots should be uniform in length (about $\frac{1}{16}$ inch) and the spaces also uniform (about $\frac{1}{32}$ inch). The next four lines are dash lines similar to those used for dimensions. These lines should be drawn with dashes about $\frac{3}{4}$ inch long and the lines should be fine, yet distinct.

The following four lines are called dot and dash lines. The dashes are about $\frac{3}{4}$ inch long and a dot between as shown. In the regular practice of drafting the length of the dashes depends upon the size of the drawing — $\frac{1}{2}$ inch to 1 inch being common. The last four lines are similar, two dots being used between the dashes. After completing the dot and dash lines, draw the border lines of the rectangle as before.

In inking *Fig. 3*, the pencil lines are followed. Great care should be exercised in starting and stopping. The lines should begin in the border lines and the end should not run over.

The lines of *Fig. 4* must be drawn carefully, as there are so many intersections. The lines in this figure should be lighter than the border lines. If every line does not coincide with the points of division L, M, N, O, P, etc., some will appear farther apart than others.

Fig. 5 is similar to *Fig. 3*, the only difference being in the angle which the oblique lines make with the horizontal.

After completing the five figures draw the border lines of the plate and then letter the plate number, date and name, and the figure numbers, as in *PLATE I.* **The plate should then be cut to the required size, 11 inches by 15 inches.**

PLATE III.

Pencilling. The horizontal and vertical center lines and the border lines for *PLATE III* are laid out in the same manner as were those of *PLATE II.* To draw the squares for the six figures, proceed as follows:

Measure off two inches on either side of the vertical center line and draw light pencil lines through these points parallel to the vertical center line. These lines will form the sides A D and B C of *Figs. 2* and *5*. Parallel to these lines and at a distance of ½ inch draw similar lines to form the sides B C of *Figs. 1* and *4* and A D of *Figs. 3* and *6*. The vertical sides A D of *Figs. 1* and *4* and B C of *Figs. 3* and *6* are formed by drawing lines perpendicular to the horizontal center line at a distance of 6½ inches from the center.

The horizontal sides D C of *Figs. 1*, *2* and *3* are drawn with the T-square ½ inch above the horizontal center line. To draw the top lines of these figures, draw (with the T-square) a line 4½ inches above the horizontal center line. The top lines of *Figs. 4*, *5* and *6* are drawn ½ inch below the horizontal center line. The squares are completed by drawing the lower lines D C, 4½ inches below the horizontal center line. The figures of *PLATES I* and *II* were constructed in rectangles; the exercises of *PLATE III* are, however, drawn in squares, having the sides 4 inches long.

In drawing *Fig. 1*, first divide A D and A B (or D C) into 4 equal parts. As these lines are four inches long, each length will be 1 inch. Now draw horizontal lines through E, F and G and vertical lines through L, M and N. These lines are shown dotted in *Fig. 1*. Connect A and B with the intersection of lines E and M, and A and D with the intersection of lines F and L. Similarly draw D J, J C, I B and I C. Also connect the points P, O, I and J forming a square. The four diamond shaped areas are formed by drawing lines from the middle points of A D, A B, B C and D C to the middle points of lines A P, A O, O B, I B etc., as shown in *Fig. 1*.

Fig. 2 is an exercise of straight lines. Divide A D and A B into four equal parts and draw horizontal and vertical lines as in *Fig. 1*. Now divide these dimensions, A L, M N, etc. and E F, G B etc. into four equal parts (each ¼ inch). Draw light pencil lines with the T-square and triangle as shown in *Fig. 2*.

In *Fig. 3*, divide A B and A D into eight parts, each length being ½ inch. Through the points H, I, J, K, L, M and N draw vertical lines with the triangle. Through O, P, Q, R, S, T and U draw horizontal lines with the T-square. Now draw lines connecting O and H, P and I, Q and J, etc. These lines can be drawn with the 45-degree triangle, as they form an angle of 45 degrees with the horizontal. Starting at N draw lines from A B to B C at an angle of 45 degrees. Also draw lines from A D to D C through the points O, P, Q, R, etc., forming angles of 45 degrees with D C.

Fig. 4 is drawn with the compasses. First draw the diagonals A C and D B. With the T-square draw the line E H. Now mark off on E H distances of ¼ inch. With the compasses set so that the point of the lead is 2 inches from the needle point, describe the circle passing through E With H as a center draw the arcs F G and I J having a radius of 1¾ inches. In drawing these arcs be careful not to go beyond the diagonals, but stop at the points F and G and I and J. Again with H as the center and a radius of 1½ inches draw a circle. The arcs K L and M N are drawn in the same manner as were arcs F G and I J; the

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PLATE III

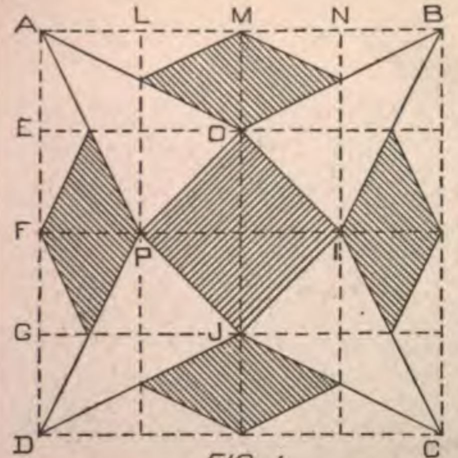

FIG I

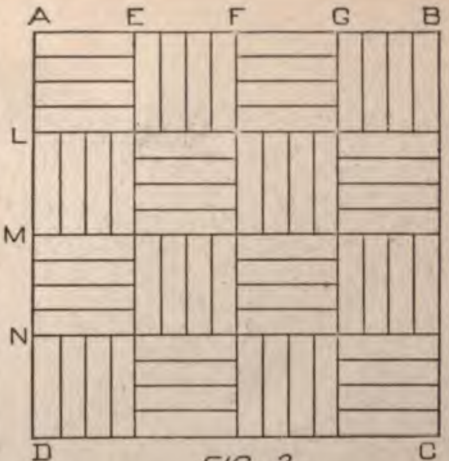

FIG. 2

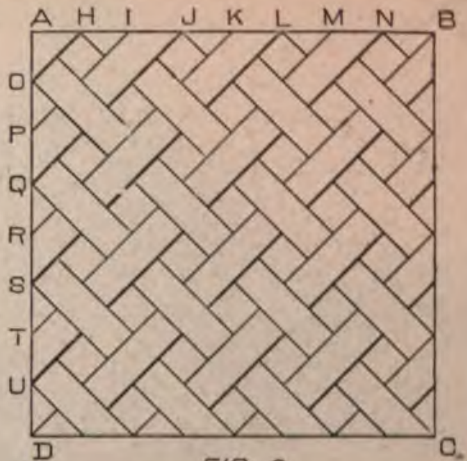

FIG. 3

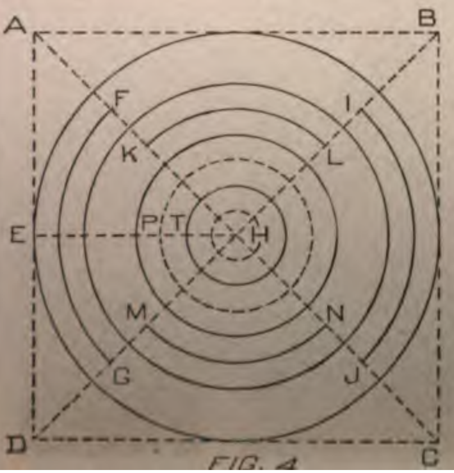

FIG. 4

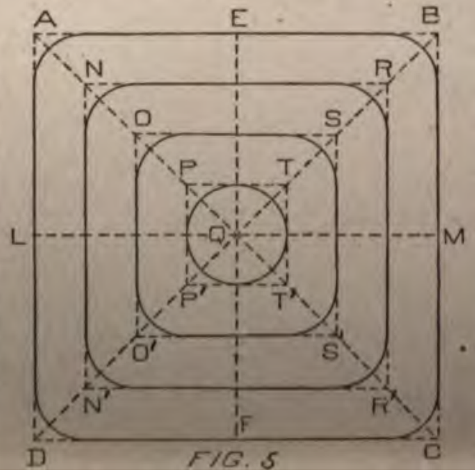

FIG. 5

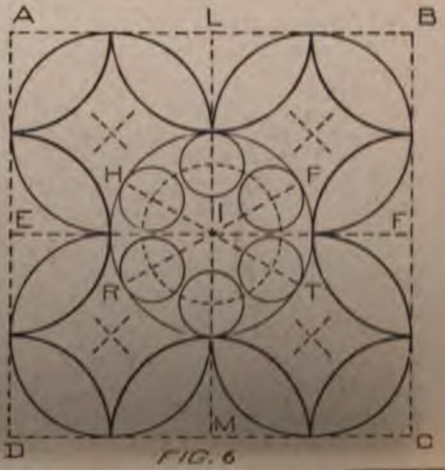

FIG. 6

CAMP OF A SURVEYING PARTY IN NEW ZEALAND

radius being $1\frac{1}{4}$ inches. Now draw circles, with H as the center, of 1, $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ inch radius, passing through the points P, T, etc.

Fig. 5 is an exercise with the line pen and compasses. First draw the diagonals A C and D B, the horizontal line L M and the vertical line E F passing through the center Q. Mark off distances of $\frac{1}{2}$ inch on L M and E F and draw the lines N N′ O O and N R, O S, etc., through these points, forming the squares N R R′ N′, O S S′ O′, etc. With the bow pencil adjusted so that the distance between the pencil point and the needle point is $\frac{1}{2}$ inch draw the arcs having centers at the corners of the squares. The arc whose center is N will be tangent to the lines A L and A E and the arc whose center is O will be tangent to N N′ and N R. Since P T, T T′, T′ P′ and P′ P are each 1 inch long and form the square, the arcs drawn with Q as a center will form a circle.

To draw *Fig. 6*, first draw the center lines E F and L M. Now find the centers of the small squares A L I E, L B F I etc. Through the center I draw the construction lines H I T and R I P forming angles of 30 degrees with the horizontal. Now adjust the compasses to draw circles having a radius of one inch. With I as a center, draw the circle H P T R. With the same radius (one inch) draw the arcs with centers at A, B, C and D. Also draw the semi-circles with centers at L, F, M and E. Now draw the arcs as shown having centers at the centers of the small squares A L I E, L B F I, etc. To locate the centers of the six small circles within the circle H P T R, draw a circle with a radius of $\frac{11}{16}$ inch and having the center in I. The small circles have a radius of $\frac{5}{16}$ inch.

Inking. In inking this plate, the outlines of the squares of the various figures are inked only in *Figs.* 2 and *3*. In *Fig. 1* the only lines to be inked are those shown in **full** lines in *PLATE III.* First ink the star and then the square and diamonds. The cross hatching should be done *without* measuring the distance between the lines and without the aid of any cross hatching device as this is an exercise for practice. The lines should be about $\frac{1}{16}$ inch apart. After inking erase all construction lines.

In inking *Fig. 2* be careful not to run over lines. Each line should coincide with the pencil line. The student should first ink the horizontal lines L, M and N and the vertical lines E, F and G. The short lines should have the same width but the border lines, A B, B C, C D and D A should be a little heavier.

Fig. 3 is drawn entirely with the 45-degree triangle. In inking the oblique lines make P I, R K, T M, etc., a light distinct line. The alternate lines O H, Q J, S L, etc., should be somewhat heavier. All of the lines which slope in the opposite direction are light. After inking *Fig. 3* all horizontal and vertical lines (except the border lines) should be erased. The border lines should be slightly heavier than the light oblique lines.

The only instrument used in inking *Fig. 4* is the compasses. In doing this exercise adjust the legs of the compasses so that the pen will always be perpendicular to the paper. If this is not done both nibs will not touch the paper and the line will be ragged. In inking the arcs, see that the pen stops *exactly* at the diagonals. The circle passing through T and the small inner circle should be dotted as shown in *PLATE III.* After inking the circles and arcs erase the construction lines that are without the outer circles but leave in *pencil* the diagonals inside the circle.

In *Fig. 5 draw all arcs first* and then draw the straight lines meeting these arcs. It is much easier to draw straight lines meeting arcs, or tangent to them, than to make the arcs tangent to straight lines. As this exercise is difficult, and in all mechanical and machine drawing arcs and tangents are frequently used we advise the beginner to draw this exercise several times. Leave all construction lines in pencil.

Fig. 6, like *Fig. 4*, is an exercise with compasses. If *Fig. 6* has been laid out accurately in pencil, the inked arcs will be tangent to each other and the finished exercise will have a good appearance. If, however, the distances were not accurately measured and the lines carefully drawn the inked arcs will not be tangent. The arcs whose centers are L, F, M and E and A, B, C and D should be heavier than the rest. The small circles may be drawn with the bow pen. After inking the arcs all construction lines should be erased.

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AN ENGINEERING SQUAD AT HEADQUARTERS

Not all the work of the surveyor is outdoor work. This view, taken in the New York City terminal offices of the New York Central Railway system, is a typical one showing the inside work which is necessary to complete that of the field parties—reduction of field notes, drawing of contour and other maps, working drawings for construction of grades, embankments, etc.

MECHANICAL DRAWING.

PART II.

GEOMETRICAL DEFINITIONS.

A **point** is used for marking position; it has neither length, breadth nor thickness.

A **line** has length only; it is produced by the motion of a point.

A *straight line* or *right line* is one that has the same direction throughout. It is the shortest distance between any two of its points.

A *curved line* is one that is constantly changing in direction. It is sometimes called a curve.

A *broken line* is one made up of several straight lines.

Parallel lines are equally distant from each other at all points.

A *horizontal line* is one having the direction of a line drawn upon the surface of water that is at rest. It is a line parallel to the horizon.

A *vertical line* is one that lies in the direction of a thread suspended from its upper end and having a weight at the lower end. It is a line that is perpendicular to a horizontal plane.

Lines are *perpendicular* to each other, if when they cross, the four angles formed are equal. If they meet and form two equal angles they are perpendicular.

An *oblique line* is one that is neither vertical nor horizontal.

In Mechanical Drawing, lines drawn along the edge of the T square, when the head of the T square is resting against the left-hand edge of the board, are called horizontal lines. Those drawn at right angles or perpendicular to the edge of the T square are called vertical.

If two lines cut each other, they are called *intersecting lines*, and the point at which they cross is called the *point of intersection*.

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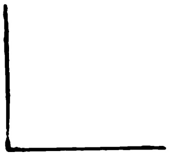
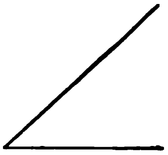
ANGLES.

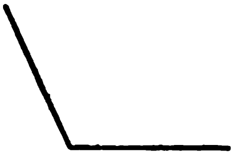
An **angle** is formed when two straight lines meet. An angle is often defined as being the difference in direction of two straight lines. The lines are called the ***sides*** and the point of meeting is called the *vertex*. The size of an angle depends upon the amount of divergence of the sides and is independent of the length of these lines.



RIGHT ANGLE.



ACUTE ANGLE.



OBTUSE ANGLE.

If one straight line meet another and the angles thus formed are equal they are **right angles.** When two lines are perpendicular to each other the angles formed are right angles.

An **acute angle** is less than a right angle.

An **obtuse angle** is greater than a right angle.

SURFACES.

A **surface** is produced by the motion of a line; it has two dimensions, — length and breadth.

A **plane figure** is a plane bounded on all sides by lines; the space included within these lines (if they are straight lines) is called a *polygon* or a *rectilinear figure.*

TRIANGLES.

A **triangle** is a figure enclosed by three straight lines. It is a polygon of three sides. The bounding lines are the ***sides***, and the points of intersection of the sides are the ***vertices***. The ***angles*** of a triangle are the angles formed by the sides.

A **right-angled** triangle, often called a ***right*** triangle, is one that has a right angle.

An **acute-angled** triangle is one that has all of its angles acute.

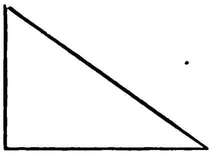
An **obtuse-angled** triangle is one that has an obtuse angle.

In an **equilateral** triangle all of the sides are equal.

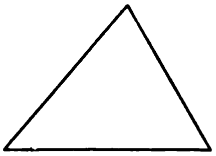
If all of the *angles* of a triangle are equal, the figure is called an **equiangular** triangle.

A triangle is called **scalene**, when no two of its sides are equal.

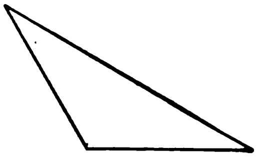
In an **isosceles** triangle two of the sides are equal.



RIGHT ANGLED TRIANGLE.



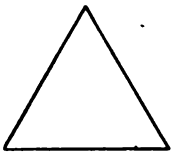
ACUTE ANGLED TRIANGLE.



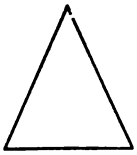
OBTUSE ANGLED TRIANGLE.

The *base* of a triangle is the lowest side ; however, any side may be taken as the base. In an isosceles triangle the side which is not one of the equal sides is usually considered the base.

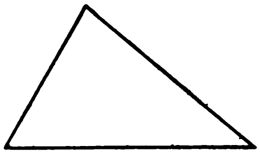
The *altitude* of a triangle is the perpendicular drawn from the vertex to the base.



EQUILATERAL TRIANGLE.



ISOSCELES TRIANGLE.

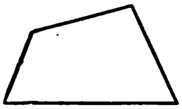


SCALENE TRIANGLE.

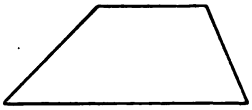
QUADRILATERALS.

A **quadrilateral** is a plane figure bounded by four straight lines.

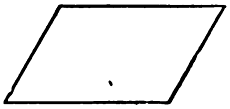
The *diagonal* of a quadrilateral is a straight line joining two opposite vertices.



QUADRILATERAL.



TRAPEZOID.



PARALLELOGRAM.

A **trapezium** is a quadrilateral, no two of whose sides are parallel.

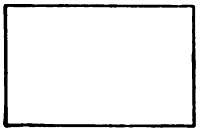
A trapezoid is a quadrilateral having two sides parallel.

The *bases* of a trapezoid are its parallel sides. The *altitude* is the perpendicular distance between the bases.

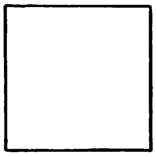
A **parallelogram** is a quadrilateral whose opposite sides are parallel.

The *altitude* of a parallelogram is the perpendicular distance between the bases which are the parallel sides.

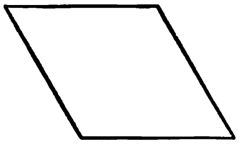
There are four kinds of parallelograms:



RECTANGLE.



SQUARE.



RHOMBUS.

A **rectangle** is a parallelogram, all of whose angles are right angles. The opposite sides are equal.

A **square** is a rectangle, all of whose sides are equal.

A **rhombus** is a parallelogram which has four equal sides; but the angles are not right angles.

A **rhomboid** is a parallelogram whose adjacent sides are unequal; the angles are not right angles.

POLYGONS.

A **polygon** is a plane figure bounded by straight lines.

The boundary lines are called the *sides* and the sum of the sides is called the *perimeter*.

Polygons are classified according to the number of sides.

A **triangle** is a polygon of *three* sides.
A **quadrilateral** is a polygon of *four* sides.
A **pentagon** is a polygon of *five* sides.
A **hexagon** is a polygon of *six* sides.
A **heptagon** is a polygon of *seven* sides.
An **octagon** is a polygon of *eight* sides.
A **decagon** is a polygon of *ten* sides.
A **dodecagon** is a polygon of *twelve* sides.

An *equilateral* polygon is one all of whose sides are equal.

An *equiangular* polygon is one all of whose angles are equal.

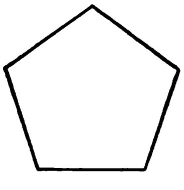
A *regular polygon* is one all of whose angles are equal and all of whose sides are equal.

CIRCLES.

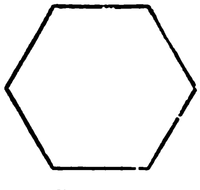
A **circle** is a plane figure bounded by a curved line, every point of which is equally distant from a point within called the center.

The curve which bounds the circle is called the **circumference** Any portion of the circumference is called an *arc.*

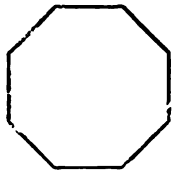
The **diameter** of a circle is a straight line drawn through the center and terminating in the circumference. A **radius** is a straight line joining the center with the circumference. It has a length equal to one half the diameter. All radii (plural of radius) are equal and all diameters are equal since a diameter equals two radii.



PENTAGON.



HEXAGON.

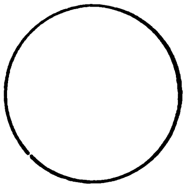


OCTAGON.

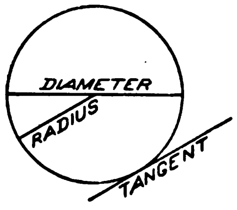
An arc equal to one-half the circumference is called a *semicircumference*, and an arc equal to one-quarter of the circumference is called a *quadrant*. A quadrant may mean the sector, arc or angle.

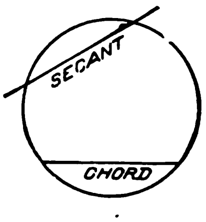
A **chord** is a straight line joining the extremities of an arc. It is a line drawn across a circle that does not pass through the center.

A **secant** is a straight line which intersects the circumference in two points.



CIRCLE.



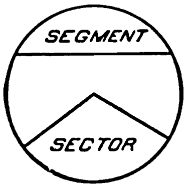


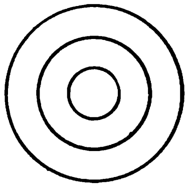
A **tangent** is a straight line which touches the circumference at only one point. It does not intersect the circumference. The point at which the tangent touches the circumference is called the ***point of tangency*** or ***point of contact.***

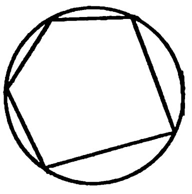
A **sector** of a circle is the portion or area included between an arc and two radii drawn to the extremities of the arc.

A **segment** of a circle is the area included between an arc and its chord.

Circles are **tangent** when the circumferences touch at only one point and are **concentric** when they have the same center.

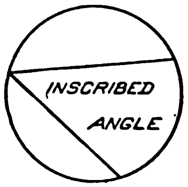


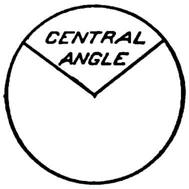

CONCENTRIC CIRCLES.

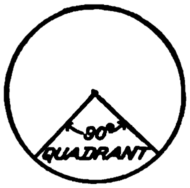

INSCRIBED POLYGON

An **inscribed angle** is an angle whose vertex lies in the circumference and whose sides are chords. It is measured by one-half the intercepted arc.

A **central angle** is an angle whose vertex is at the center of the circle and whose sides are radii.





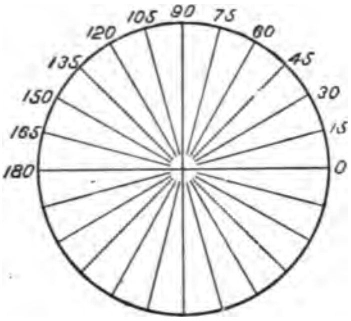


An **inscribed polygon** is one whose vertices lie in the circumference and whose sides are chords.

MEASUREMENT OF ANGLES.

To measure an angle describe an arc with the center at the vertex of the angle and having any convenient radius. The portion of the arc included between the sides of the angle is the measure of the angle. If the arc has a constant radius the greater the divergence of the sides, the longer will be the arc. If there are several arcs drawn with the same center, the intercepted arcs will have different lengths but they will all be the *same fraction* of the entire circumference.

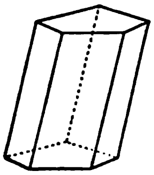
In order that the size of an angle or arc may be stated without saying that it is a certain fraction of a circumference, the circumference is divided into 360 equal parts called degrees. Thus we can say that an angle contains 45 degrees, which means that it is $\frac{45}{360} = \frac{1}{8}$ of a circumference. In order to obtain accurate measurements each degree is divided into 60 equal parts called *minutes* and each minute is divided into 60 equal parts called *seconds*. Angles and arcs are usually measured by means of an instrument called a protractor which has already been explained.



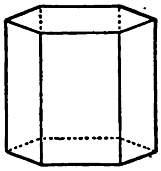
SOLIDS.

A **polyedron** is a solid bounded by planes. The bounding planes are called the *faces* and their intersections *edges*. The intersections of the edges are called *vertices*.

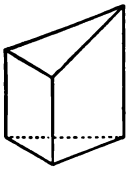
A polygon having four faces is called a **tetraedron**; one having six faces a **hexaedron**; of eight faces an **octaedron**; of twelve faces a **dodecaedron**, etc.



PRISM.



RIGHT PRISM.



TRUNCATED PRISM.

A **prism** is a polyedron, of which two opposite faces, called bases, are equal and parallel; the other faces, called lateral faces are parallelograms.

The area of the lateral faces is called the *lateral area*.

The *altitude* of a prism is the perpendicular distance between the bases.

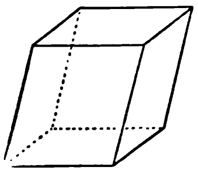
Prisms are *triangular*, *quadrangular*, etc., according to the shape of the base.

A **right** prism is one whose lateral edges are perpendicular to the bases.

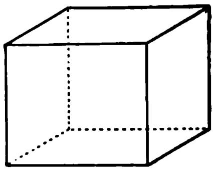
A **regular** prism is a right prism having regular polygons for bases.

A **parallelopiped** is a prism whose bases are parallelograms. If the edges are all perpendicular to the bases it is called a **right** parallelopiped.

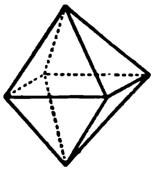
A **rectangular parallelopiped** is a right parallelopiped whose bases are rectangles; all the faces are rectangles.



PARALLELOPIPED.



RECTANGULAR PARALLELOPIPED.



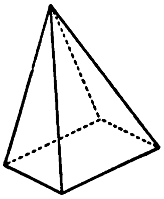
OCTAEDRON.

A **cube** is a rectangular parallelopiped all of whose faces are squares.

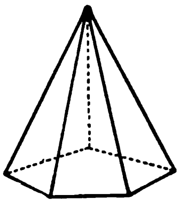
A **truncated prism** is the portion of a prism included between the base and a plane not parallel to the base.

PYRAMIDS.

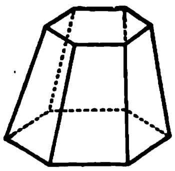
A **pyramid** is a polyedron one face of which is a polygon (called the base) and the other faces are triangles having a common vertex.



PYRAMID.



REGULAR PYRAMID.



FRUSTUM OF PYRAMID.

The vertices of the triangles form the *vertex* of the pyramid.

The *altitude* of the pyramid is the perpendicular distance from the vertex to the base.

A pyramid is called **triangular, quadrangular,** etc., according to the shape of the base.

A **regular pyramid** is one whose base is a regular polygon and whose vertex lies in the perpendicular erected at the center of the base.

A **truncated pyramid** is the portion of a pyramid included between the base and a plane not parallel to the base.

A **frustum** of a pyramid is the solid included between the base and a plane parallel to the base.

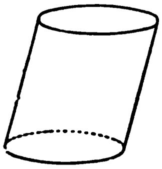
The *altitude* of a frustum of a pyramid is the perpendicular distance between the bases.

CYLINDERS.

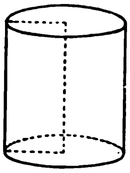
A **cylindrical surface** is a curved surface generated by the motion of a straight line which touches a curve and continues parallel to itself.

A **cylinder** is a solid bounded by a cylindrical surface and two parallel planes intersecting this surface.

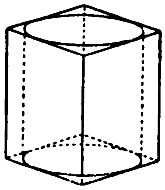
The parallel faces are called *bases*.



CYLINDER.



RIGHT CYLINDER.



INSCRIBED CYLINDER.

The *altitude* of a cylinder is the perpendicular distance between the bases.

A **circular cylinder** is a cylinder whose base is a circle.

A **right cylinder** or a *cylinder of revolution* is a cylinder generated by the revolution of a rectangle about one side as an axis.

A prism whose base is a regular polygon may be inscribed in or circumscribed about a circular cylinder.

The cylindrical area is call the *lateral area*. The *total area* is the area of the bases added to the lateral area.

CONES.

A **conical surface** is a curved surface generated by the motion of a straight line, one point of which is fixed and the end or ends of which move in a curve.

A **cone** is a solid bounded by a conical surface and a plane which cuts the conical surface.

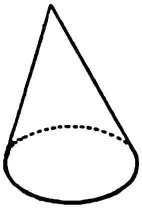
The plane is called the *base* and the curved surface the lateral area.

The *vertex* is the fixed point.

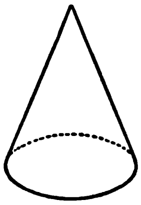
The *altitude* of a cone is the perpendicular distance from the vertex to the base.

An *element* of a cone is a straight line from the vertex to the perimeter of the base.

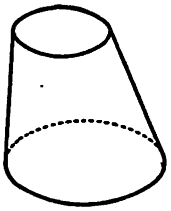
A **circular cone** is a cone whose base is a circle.



CONE.



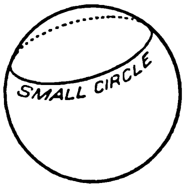
RIGHT CIRCULAR CONE.



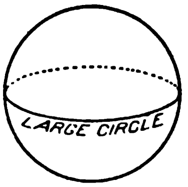
FRUSTUM OF CONE.

A **right circular cone** or **cone of revolution** is a cone whose axis is perpendicular to the base. It may be generated by the revolution of a right triangle about one of the perpendicular sides as an axis.

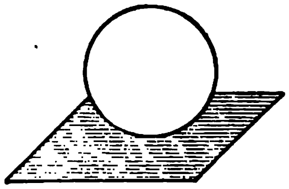
A **frustum** of a cone is the solid included between the base and a plane parallel to the base.



SPHERE.



SPHERE.



TANGENT PLANE.

The *altitude* of a frustum of a cone is the perpendicular distance between the bases.

SPHERES.

A **sphere** is a solid bounded by a curved surface, every point of which is equally distant from a point within called the center.

The *radius* of a sphere is a straight line drawn from the center to the surface. The *diameter* is a straight line drawn through the center and having its extremities in the surface.

A sphere may be generated by the revolution of a semi-circle about its diameter as an axis.

An *inscribed polyedron* is a polyedron whose vertices lie in the surface of the sphere.

An *circumscribed polyedron* is a polyedron whose faces are tangent to a sphere.

A *great circle* is the intersection of the spherical surface and a plane passing through the center of a sphere.

A *small circle* is the intersection of the spherical surface and a plane which does not pass through the center.

A sphere is *tangent* to a plane when the plane touches the surface in only one point. A plane perpendicular to the extremity of a radius is tangent to the sphere.

CONIC SECTIONS.

If a plane intersects a cone the geometrical figures thus formed are called conic sections. A plane perpendicular to the base and passing through the vertex of a right circular cone forms an isosceles triangle. If the plane is parallel to the base the intersection of the plane and conical surface will be the circumference of a circle.

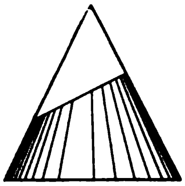


Fig. 1.

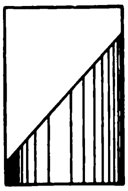


Fig. 2.

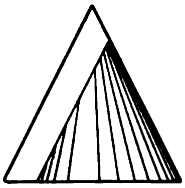


Fig. 3.

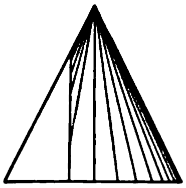


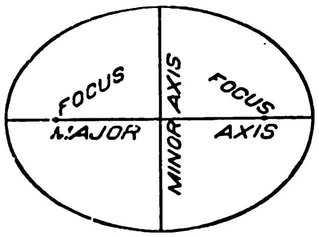
Fig. 4.

Ellipse. The ellipse is a curve formed by the intersection of a plane and a cone, the plane being oblique to the axis but not cutting the base. If a plane is passed through a cone as shown in Fig. 1 or through a cylinder as shown in Fig 2, the curve of intersection will be an ellipse. An ellipse may be defined as being *a curve generated by a point moving in a plane, the sum of the distances of the point to two fixed points being always constant.*

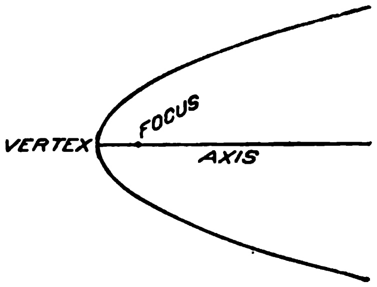
The two fixed points are called the **foci** and lie on the longest line that can be drawn in the ellipse. One of these points is called a *focus.*

The longest line that can be drawn in an ellipse is called the **major axis** and the shortest line, passing through the center, is called the **minor axis.** The minor axis is perpendicular to the middle point of the major axis and the point of intersection is called the center

An ellipse may be constructed if the major and minor axes are given or if the foci and one axis are known.



ELLIPSE.

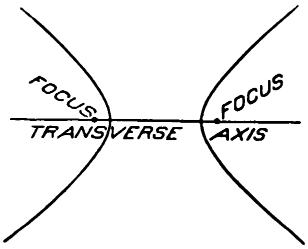


PARABOLA.

Parabola. The parabola is a curve formed by the intersection of a cone and a plane parallel to an element as shown in Fig. 3. The curve is not a closed curve. The branches approach parallelism.

A parabola may be defined as being *a curve every point of which is equally distant from a line and a point.*

The point is called the **focus** and the given line the **directrix.** The line perpendicular to the directrix and passing through the focus is the **axis.** The intersection of the axis and the **curve** is the **vertex.**



HYPERBOLA.

Hyperbola. This curve is formed by the intersection of a plane and a cone, the plane being parallel to the axis of the cone as shown in Fig. 4. Like the parabola, the curve is not a closed curve; the branches constantly diverge.

An hyperbola is defined as being *a plane curve such that the difference of the distances from any point in the curve to two fixed points is equal to a given distance.*

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The two fixed points are the **foci** and the line passing through them is the **transverse axis.**

Rectangular Hyperbola. The form of hyperbola most used in Mechanical Engineering is called the rectangular hyperbola because it is drawn with reference to rectangular co-ordinates. This curve is constructed as follows: In Fig. 5, O X and O Y are the two co-ordinates drawn at right angles to each other. These lines are also called axes or asymptotes. Assume A to be a known point on the curve. In drawing this curve for the theoretical indicator card, this point A is the point of cut-off.

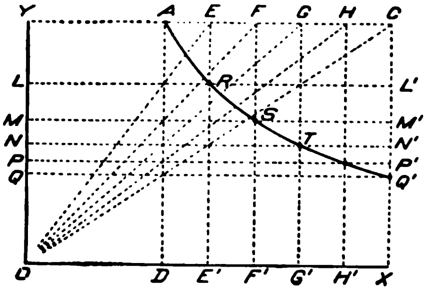


Fig. 5.

Draw A C parallel to O X and A D perpendicular to O X. Now mark off any convenient points on A C such as E, F, G, and H; and through these points draw EE′, FF′, GG′, and HH′ perpendicular to O X. Connect E, F, G, H and C with O. Through the points of intersection of the oblique lines and the vertical line A D draw the horizontal lines LL′, MM′, NN′, PP′ and QQ′. The first point on the curve is the assumed point A, the second point is R, the intersection of LL′ and EE′. The third is the intersection S of MM′ and FF′; the fourth is the intersection T of NN′ and GG′. The other points are found in the same way.

In this curve the products of the co-ordinates of all points are equal. Thus $LR \times RE' = MS \times SF' = NT \times TG'$.

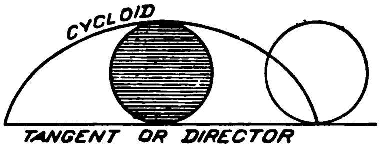
ODONTOIDAL CURVES.

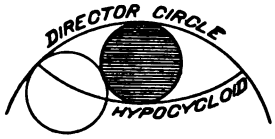
The outlines of the teeth of gears must be drawn accurately because the smoothness of running depends upon the shape of the teeth. The two classes of curves generally employed in drawing gear teeth are the cycloidal and involute.

Cycloid. The cycloid is a curve generated by a point on the circumference of a circle which rolls on a straight line tangent to the circle.

The rolling circle is called the *describing* or *generating circle* and the point, the *describing* or *generating point.* The tangent along which the circle rolls is called the *director.*

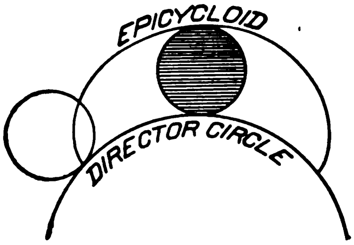
In order that the curve may be a true cycloid the circle must roll without any slipping.

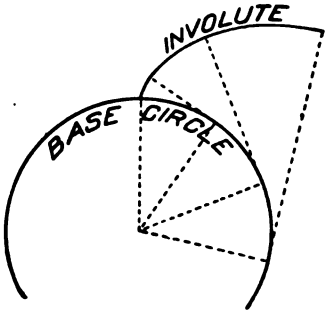




Epicycloid. If the generating circle rolls upon the *outside* of an arc or circle, called the *director circle,* the curve thus generated is called an epicycloid. The method of drawing this curve is the same as that for the cycloid.

Hypocycloid. In case the generating circle rolls upon the inside of an arc or circle, the curve thus generated is called the hypocycloid. The circle upon which the generating circle rolls is called the *director circle.* If the generating circle has a diameter equal to the radius of the director circle the hypocycloid becomes a straight line.





Involute. If a thread or fine wire is wound around a cylinder or circle and then unwound, the end will describe a curve called an involute. The involute may be defined as being *a curve generated by a point in a tangent rolling on a circle known as the base circle.*

The construction of the ellipse, parabola, hyperbola and odontoidal curves will be taken up in detail with the plates.

PLATE IV.

Pencilling. The horizontal and vertical center lines and the border lines for *PLATE IV* should be laid out in the same manner as were those for *PLATE I.* There are to be six figures on this plate and to facilitate the laying out of the work, the following lines should be drawn: measure off 2¼ inches on both sides of the vertical center line and through these points draw vertical lines as shown in dot and dash lines on *PLATE IV.* In these six spaces the six figures are to be drawn, the student placing them in the centers of the spaces so that they will present a good appearance. In locating the figures, they should be placed a little above the center so that there will be sufficient space below to number the problem.

The figures of the problems should first be drawn lightly in pencil and after the entire plate is completed the lines should be inked. In pencilling, all intersections must be formed with great care as the accuracy of the results depends upon the pencilling. Keep the pencil points in good order at all times and draw lines *exactly* through intersections.

GEOMETRICAL PROBLEMS.

The following problems are of great importance to the mechanical draughtsman. The student should solve them with care; he should not do them blindly, but should understand them so that he can apply the principles in later work.

PROBLEM I. **To Bisect a Given Straight Line.**

Draw the horizontal straight line A C about 3 inches long. With the extremity A as a center and any convenient radius (about 2 inches) describe arcs above and below the line A C. With the other extremity C as a center and with the same radius draw short arcs above and below A C intersecting the first arcs at D and E. The radius of these arcs must be greater than one-half the length of the line in order that they may intersect. Now draw the straight line D E passing through the intersections D and E. This line cuts the line A C at F which is the middle point.

$$AF = FC$$

Proof. Since the points D and E are equally distant from A and C a straight line drawn through them is perpendicular to A C at its middle point F.

PROBLEM 2. **To Construct an Angle Equal to a Given Angle.**

Draw the line O C about 2 inches long and the line O A of about the same length. The angle formed by these lines may be any convenient size (about 45 degrees is suitable). This angle A O C is the given angle.

Now draw F G a horizontal line about 2¼ inches long and let F the left-hand extremity be the vertex of the angle to be constructed.

With O as a center and any convenient radius (about 1¼ inches) describe the arc L M cutting both O A and O C. With F as a center and the same radius draw the indefinite arc O Q. Now set the compass so that the distance between the pencil and the needle point is equal to the chord L M. With Q as a center and a radius equal to L M draw an arc cutting the arc O Q at P. Through F and P draw the straight line F E. The angle E F G is the required angle since it is equal to A O C.

Proof. Since the chords of the arcs L M and P Q are equal the arcs are equal. The angles are equal because with equal radii equal arcs are intercepted by equal angles.

PROBLEM 3. **To Draw Through a Given Point a Line Parallel to a Given Line.**

First Method. Draw the horizontal straight line A C about 3½ inches long and assume the point P about 1¼ inches above A C. Through the point P draw an oblique line F E forming any convenient angle with A C. (Make the angle about 60 degrees). Now construct an angle equal to P F C having the vertex at P and one side the line E P. (See problem 2). This may be done as follows: With F as a center and any convenient radius, describe the arc L M. With the same radius draw the indefinite arc N O using P as the center. With N as a center and a radius equal to the chord L M, draw an arc cutting the arc N O at O. Through the points P and O draw a straight line which will be parallel to A C.

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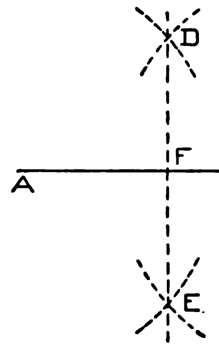
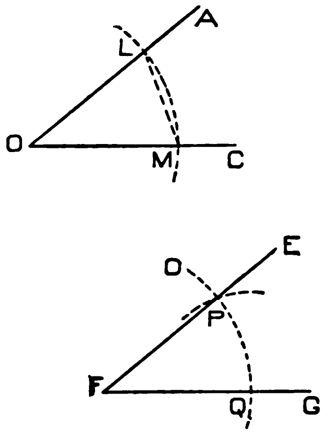
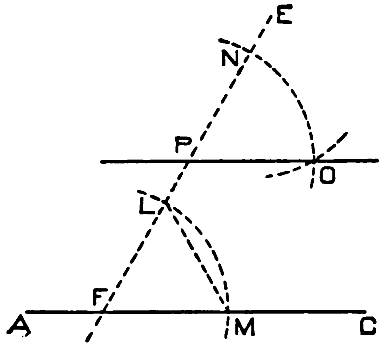
PLATE IV



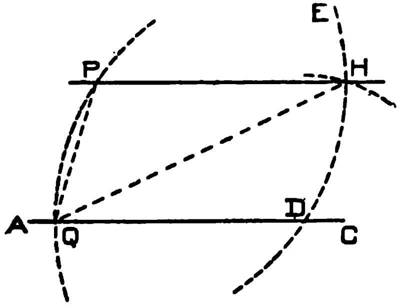
Problem 1



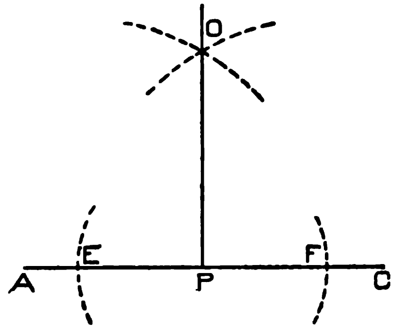
Problem 2



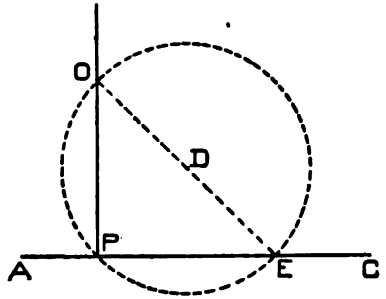
Problem 3



Problem 4



Problem 5



Problem 6

Proof. If two straight lines are cut by a third making the corresponding angles equal, the lines are parallel.

PROBLEM 4. **To Draw Through a Given Point a Line Parallel to a Given Line.**

Second Method. Draw the straight line A C about 3¼ inches long and assume the point P about 1½ inches above A C. With P as a center and any convenient radius (about 2½ inches) draw the indefinite arc E D cutting the line A C. Now with the same radius and with D as a center, draw an arc P Q. Set the compass so that the distance between the needle point and the pencil is equal to the chord P Q. With D as a center and a radius equal to P Q, describe an arc cutting the arc E D at H. A line drawn through P and H will be parallel to A C.

Proof. Draw the line Q H. Since the arcs P Q and H D are equal and have the same radii, the angles P H Q and H Q D are equal. Two lines are parallel if the alternate interior angles are equal.

PROBLEM 5. **To Draw a Perpendicular to a Line from a Point in the Line.**

First Method. When the point is near the middle of the line.

Draw the horizontal line A C about 3½ inches long and assume the point P near the middle of the line. With P as a center and any convenient radius (about 1¼ inches) draw two arcs cutting the line A C at E and F. Now with E and F as centers and any convenient radius (about 2½ inches) describe arcs intersecting at O. The line O P will be perpendicular to A C at P.

Proof. The points P and O are equally distant from E and F. Hence a line drawn through them is perpendicular to the middle point of E F which is P.

PROBLEM 6. **To Draw a Perpendicular to a Line from a Point in the Line.**

Second Method. When the point is near the end of the line.

Draw the line A C about 3½ inches long. Assume the given point P to be about ¾ inch from the end A. With any point D as a center and a radius equal to D P, describe an arc, cutting A C at E. Through E and D draw the diameter E O. A line from O to P is perpendicular to A C at P.

Proof. The angle O P E is inscribed in a semi-circle; hence it is a right angle, and the sides O P and P E are perpendicular to each other.

After completing these figures draw pencil lines for the lettering. The words "*PLATE IV*" and the date and name should be placed in the border, as in preceding plates. To letter the words "Problem 1," "Problem 2," etc., draw horizontal lines $\frac{1}{4}$ inch above the horizontal center line and the lower border line. Draw another line $\frac{3}{16}$ inch above, to limit the height of the P, *b* and *l*. Draw a third line $\frac{1}{8}$ inch above the lower line as a guide line for the tops of the small letters.

Inking. In inking *PLATE IV* the figures should be inked first. The line A C of Problem 1 should be a full line as it is the given line; the arcs and line D E, being construction lines should be dotted. In Problem 2, the sides of the angles should be full lines. Make the chord L M and the arcs dotted, since as before, they are construction lines.

In Problem 3, the line A C is the given line and P O is the line drawn parallel to it. As E F and the arcs do not form a part of the problem but are merely construction lines, drawn as an aid in locating P O, they should be dotted. In Problems 4, 5 and 6, the assumed lines and those found by means of the construction lines should be full lines. The arcs and construction lines should be dotted. In Problem 6, the entire circumference need not be inked, only that part is necessary that is used in the problem. The inked arc should however be of sufficient length to pass through the points O, P and E.

After inking the figures, the border lines should be inked with a heavy line as before. Also, the words "*PLATE IV*" and the date and the student's name. Under each problem the words "Problem 1," "Problem 2," etc., should be inked; lower case letters being used as shown.

PLATE V.

Pencilling. In laying out the border lines and centre lines follow the directions given for *PLATE IV*. The dot and dash lines should be drawn in the same manner as there are to be six problems on this plate.

PROBLEM 7. **To Draw a Perpendicular to a Line from a Point without the Line.**

Draw the horizontal straight line A C about 3¼ inches long. Assume the point P about 1½ inches above the line. With P as a center and any convenient radius (about 2 inches) describe an arc cutting A C at E and F. The radius of this arc must always be such that it will cut A C in two points; the nearer the points E and F are to A and C, the greater will be the accuracy of the work. Now with E and F as centers and any convenient radius (about 2¼ inches) draw the arcs intersecting below A C at T. A line through the points P and T will be perpendicular to A C.

In case there is not room below A C to draw the arcs, they may be drawn intersecting above the line as shown at N. Whenever convenient, draw the arcs below A C for greater accuracy.

Proof. Since P and T are equally distant from E and F, the line P T is perpendicular to A C.

PROBLEM 8. **To Bisect a Given Angle.**

First Method. When the sides intersect.

Draw the lines O C and O A forming any angle (from 45 to 60 degrees). These lines should be about 3 inches long. With O as a center and any convenient radius (about 2 inches) draw an arc intersecting the sides of the angle at E and F. With E and F as centers and a radius of 1½ or 1¾ inches, describe short arcs intersecting at I. A line O D, drawn through the points O and I, bisects the angle.

In solving this problem the arc E F should not be too near the vertex if accuracy is desired.

Proof. The central angles A O D and D O C are equal because the arc E F is bisected by the line O D. The point I is equally distant from E and F.

PROBLEM 9. **To Bisect a Given Angle.**

Second Method. When the lines do not intersect.

Draw the lines A C and E F about 4 inches long and in the positions as shown on *PLATE V.* Draw A′ C′ and E′ F′ parallel to A C and E F and at such equal distances from them that they will intersect at O. Now bisect the angle C′ O F′ by the method of Problem 8. Draw the arc G H and with G and H as centers draw the arcs intersecting at R. The line O R bisects the angle.

Proof. Since A′ C′ is parallel to A C and E′ F′ parallel to E F, the angle C′ O F′ is equal to the angle formed by the lines A C and E F. Hence as O R bisects angle C′ O F′ it also bisects the angle formed by the lines A C and E F.

PROBLEM 10. To Divide a Given Line into any Number of Equal Parts.

Let A C, about 3¾ inches long, be the given line. Let us divide it into 7 equal parts. Draw the line A J at least 4 inches long, forming any convenient angle with A C. On A J lay off, by means of the dividers or scale, points D, E, F, G, etc., each ½ inch apart. If dividers are used the spaces need not be exactly ½ inch. Draw the line J C and through the points D, E, F, G, etc., draw lines parallel to J C. These parallels will divide the line A C into 7 equal parts.

Proof. If a series of parallel lines, cutting two straight lines, intercept equal distances on one of these lines, they also intercept equal distances on the other.

PROBLEM 11. To Construct a Triangle having given the Three Sides.

Draw the three sides as follows:

A C,	$2\frac{3}{4}$ inches long.
E F,	$1\frac{15}{16}$ inches long.
M N,	$2\frac{3}{16}$ inches long.

Draw R S equal in length to A C. With R as a center and a radius equal to E F describe an arc. With S as a center and a radius equal to M N draw an arc cutting the arc previously drawn, at T. Connect T with R and S to form the triangle.

PROBLEM 12. To Construct a Triangle having given One Side and the Two Adjacent Angles.

Draw the line M N 3¼ inches long and draw two angles A O D and E F G. Make the angle A O D about 30 degrees and E F G about 60 degrees.

Draw R S equal in length to M N and at R construct an

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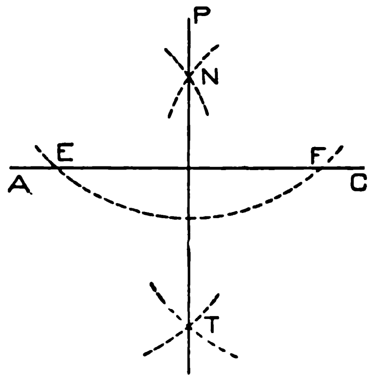
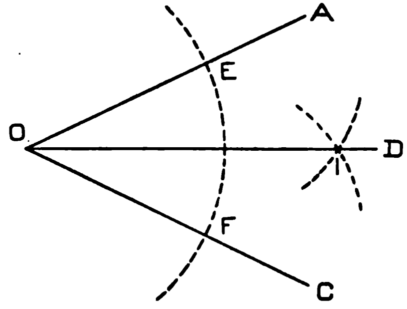
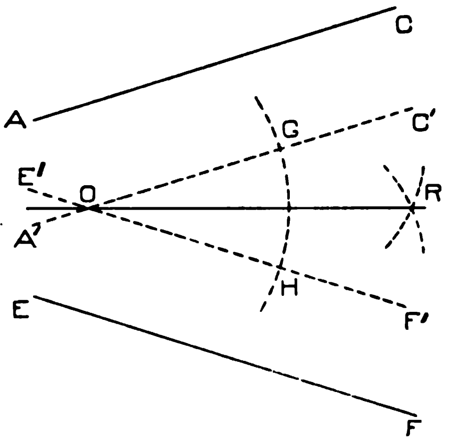
PLATE V



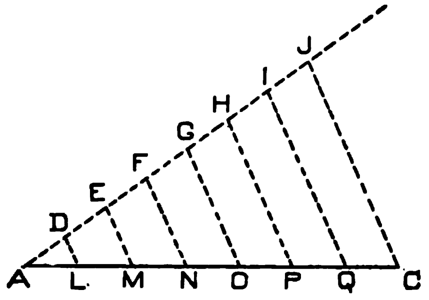
Problem 7



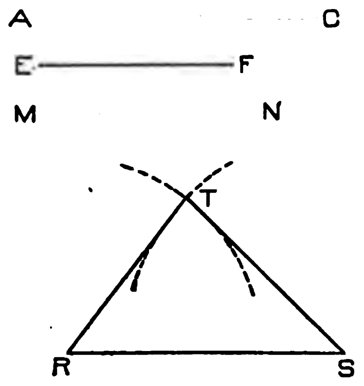
Problem 8



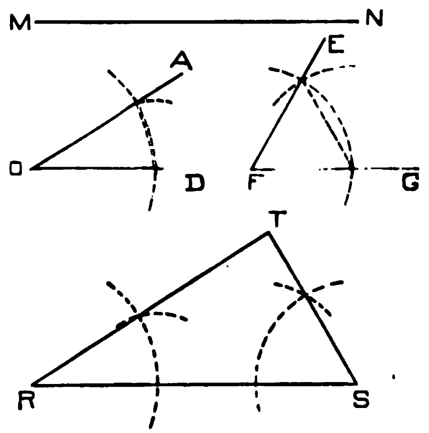
Problem 9



Problem 10



Problem 11



Problem 12

JANUARY 19, 1907
HERBERT CHANDLER
CHICAGO, ILL.

angle equal to A O D. At S construct an angle equal to E F G by the method used in Problem 2. *PLATE V* shows the necessary arcs. Produce the sides of the angles thus constructed until they meet at T. The triangle R T S will be the required triangle.

After drawing these six figures in pencil, draw the pencil lines for the lettering. The lines for the words "*PLATE V*," date and name, should be pencilled as explained on page 20. The words "Problem 7," "Problem 8," etc., are lettered as for *PLATE IV.*

Inking. In inking *PLATE V*, the same principles should be followed as stated with *PLATE IV.* The student should apply these principles and not make certain lines dotted just because they are shown dotted in *PLATE V.*

After inking the figures, the border lines should be inked and the lettering inked as already explained in connection with previous plates.

PLATE VI.

Pencilling. Lay out this plate in the same manner as the two preceding plates.

PROBLEM 13. **To describe an Arc or Circumference through Three Given Points not in the same straight line.**

Locate the three points A, B and C. Let the distance between A and B be about 2 inches and the distance between A and C be about 2¼ inches. Connect A and B and A and C. Erect perpendiculars to the middle points of A B and A C. This may be done as explained with Problem 1. With A and B as centers and a radius of about 1½ inches, describe the arcs intersecting at I and J. With A and C as centers and with a radius of about 1¾ inches draw the arcs, intersecting at E and F. Now draw light pencil lines connecting the intersections I and J and E and F. These lines will intersect at O.

With O as a center and a radius equal to the distance O A, describe the circumference passing through A, B and C.

Proof. The point O is equally distant from A, B and C, since it lies in the perpendiculars to the middle points of A B and

A C. Hence the circumference will pass through A, B and C.

PROBLEM 14. **To inscribe a Circle in a given Triangle.**

Draw the triangle L M N of any convenient size. M N may be made 3¼ inches, L M, 2¾ inches, and L N, 3½ inches. Bisect the angles M L N and L M N. The bisectors M I and L J may be drawn by the method used in Problem 8. Describe the arcs A C and E F, having centers at L and M respectively. The arcs intersecting at I and J are drawn as already explained. The bisectors of the angles intersect at O, which is the center of the inscribed circle. The radius of the circle is equal to the perpendicular distance from O to one of the sides.

Proof. The point of intersection of the bisectors of the angles of a triangle is equally distant from the sides.

PROBLEM 15. **To inscribe a Regular Pentagon in a given Circle.**

With O as a center and a radius of about 1½ inches, describe the given circle. With the T square and triangles draw the center lines A C and E F. These lines should be perpendicular to each other and pass through O. Bisect one of the radii, such as O C, and with this point H as a center and a radius H E, describe the arc E P. This arc cuts the diameter A C at P. With E as a center and a radius E P, draw arcs cutting the circumference at L and Q. With the same radius and a center at L, draw the arc, cutting the circumference at M. To find the point N, use either M or Q as a center and the distance E P as a radius.

The pentagon is completed by drawing the chords E L, L M, M N, N Q and Q E.

PROBLEM 16. **To inscribe a Regular Hexagon in a given Circle.**

With O as a center and a radius of 1⅜ inches draw the given circle. With the T square draw the diameter A D. With D as a center, and a radius equal to O D, describe arcs cutting the circumference at C and E. Now with C and E as centers and the same radius, draw the arcs, cutting the circumference at B and F. Draw the hexagon by joining the points thus formed.

To inscribe a regular hexagon in a circle mark off chords equal in length to the radius.

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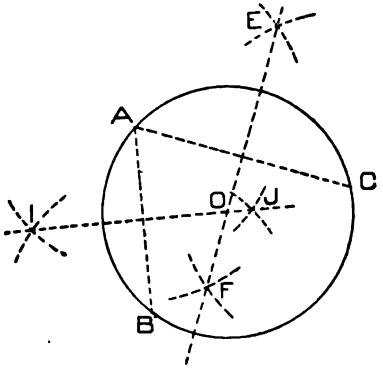
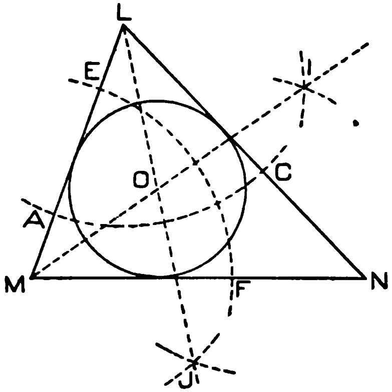
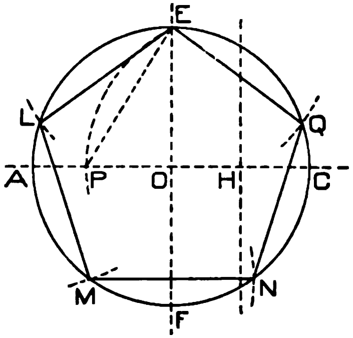
PLATE VI



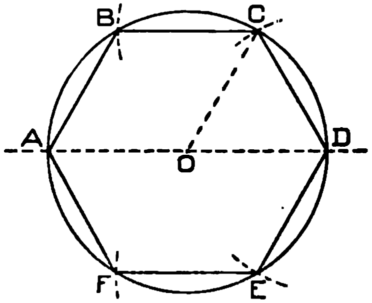
Problem 13



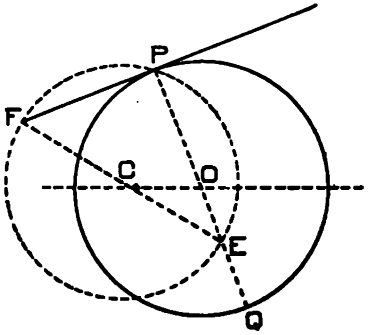
Problem 14



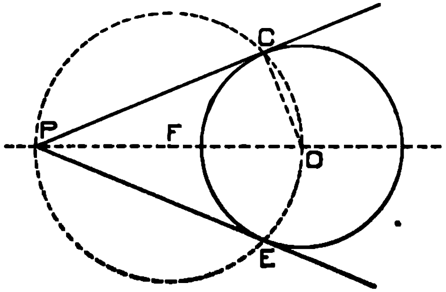
Problem 15



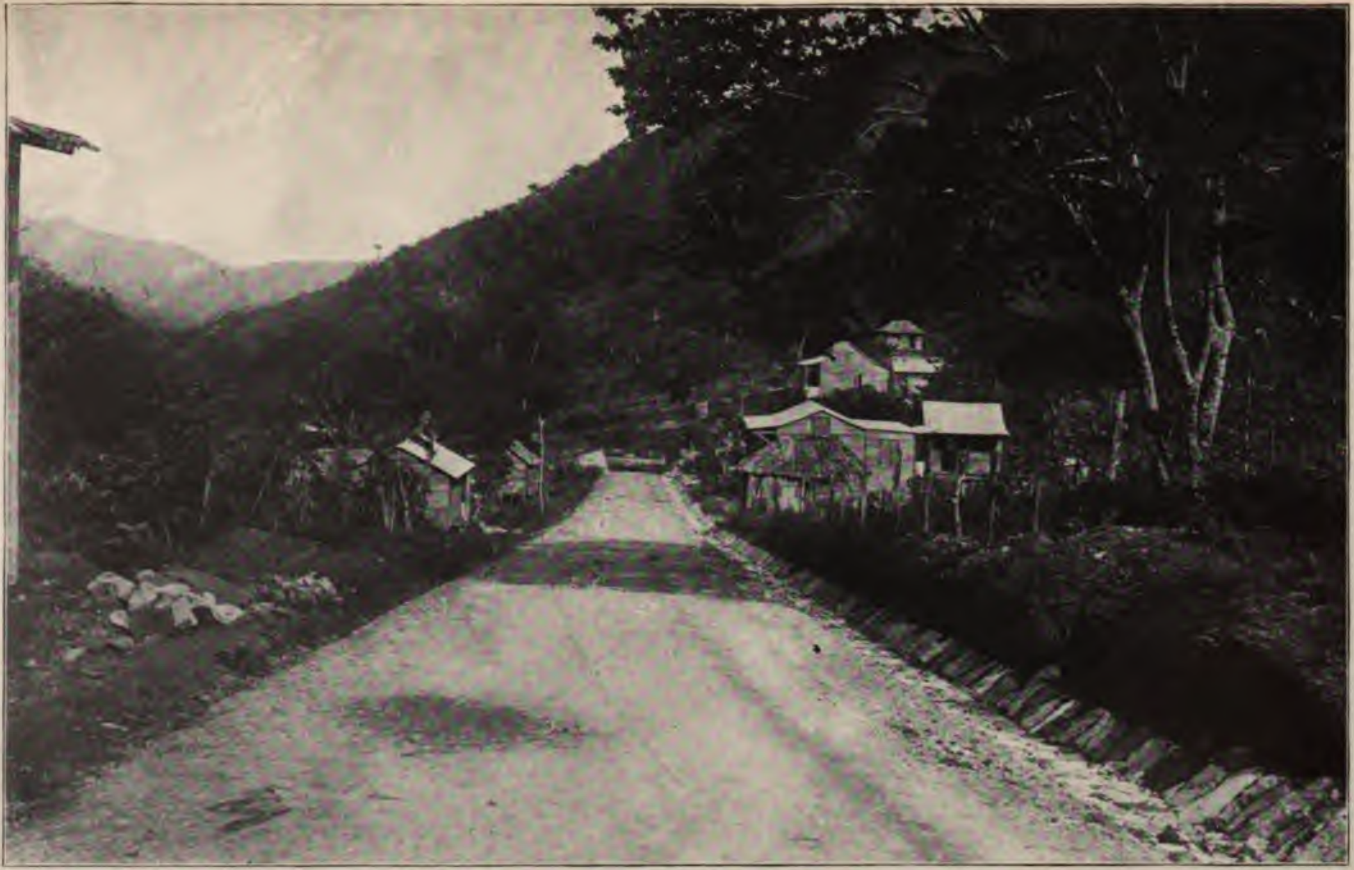
Problem 16



Problem 17



Problem 18



ROAD-BUILDING IN PORTO RICO

Stretch of finished road south of Adjuntas. Paved gutter shown at right.

To inscribe an equilateral triangle in a circle the same method may be used. The triangle is formed by joining the opposite vertices of the hexagon.

Proof. The triangle O C D is an equilateral triangle by construction. Then the angle C O D is one-third of two right angles and one-sixth of four right angles. Hence arc C D is one-sixth of the circumference and the chord is a side of a regular hexagon.

PROBLEM 17. **To draw a line Tangent to a Circle at a given point on the circumference.**

With O as a center and a radius of about 1¼ inches draw the given circle. Assume some point P on the circumference Join the point P with the center O and through P draw a line F P perpendicular to P O. This may be done in any one of several methods. Since P is the extremity of O P the method given in Problem 6 of *PLATE IV*, may be used.

Produce P O to Q. With any center C, and a radius C P draw an arc or circumference passing through P. Draw E F a diameter of the circle whose center is C and through F and P draw the tangent.

Proof. A line perpendicular to a radius at its extremity is tangent to the circle.

PROBLEM 18. **To draw a line Tangent to a Circle from a point outside the circle.**

With O as a center and a radius of about 1 inch draw the given circle. Assume P some point outside of the circle about 2½ inches from the center of the circle. Draw a straight line passing through P and O. Bisect P O and with the middle point F as a center describe the circle passing through P and O. Draw a line through P and the intersection of the two circumferences C. The line P C is tangent to the given circle. Similarly P E is tangent to the circle.

Proof. The angle P C O is inscribed in a semi-circle and hence is a right angle. Since P C O is a right angle P C is perpendicular to C O. The perpendicular to a radius at its extremity is tangent to the circumference.

Inking. In inking *PLATE VI* the same method should be followed as in previous plates. The name and address should be lettered in inclined Gothic capitals as before.

PLATE VII.

Pencilling. *PLATE VII* should be laid out in the same manner as previous plates. Six problems on the ellipse, spiral, parabola and hyperbola are to be constructed in the six spaces.

PROBLEM 19. **To draw an Ellipse when the Axes are given.**

Draw the lines L M and C D about $3\frac{1}{4}$ and $2\frac{1}{4}$ inches long respectively. Let C D be perpendicular to M N at its middle point P. Make C P = P D. These two lines are the axes. With C as a center and a radius equal to one-half the major axis or equal to L P, draw the arc, cutting the major axis at E and F. These two points are the foci. Now mark off any convenient distances on P M, such as A, B and G.

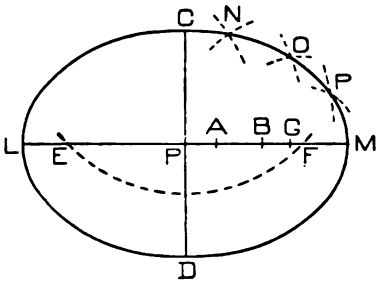
With E as a center and a radius equal to L A, draw arcs above and below L M. With F as a center, and a radius equal to A M describe short arcs cutting those already drawn as shown at N. With E as a center and a radius equal to L B draw arcs above and below L M as before. With F as a center and a radius equal to B M, draw arcs intersecting those already drawn as shown at O. The point P and others are found by repeating the process. The student is advised to find at least 12 points on the curve — 6 above and 6 below L M. These 12 points with L, C, M and D will enable the student to draw the curve.

After locating these points, a free hand curve passing through them should be sketched.

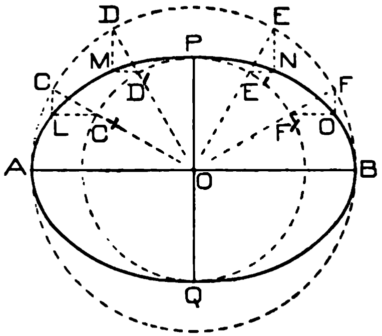
PROBLEM 20. **To draw an Ellipse when the two Axes are given.**

Second Method. Draw the two axes A B and P Q in the same manner as for Problem 19. With O as a center and a radius equal to one-half the major axis, describe the circumference A C D E F B. Similarly with the same center and a radius equal to one-half the minor axis, describe a circle. Draw any radii such as O C, O D, O E, O F, etc., cutting both circumferences. These radii may be drawn with the 60 and 45 degree triangles. At the

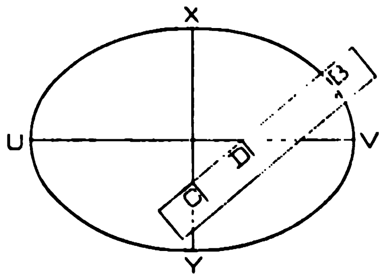
PLATE VII



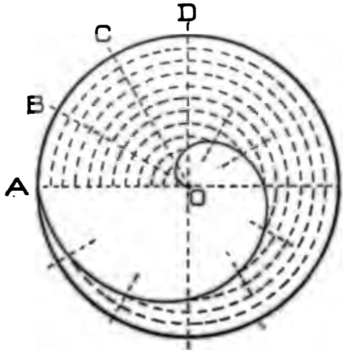
Problem 19



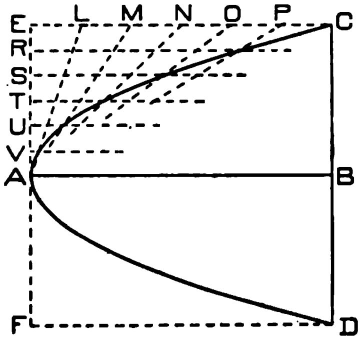
Problem 20



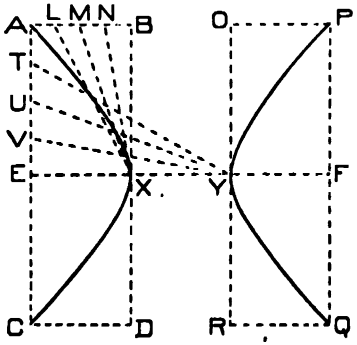
Problem 21



Problem 22



Problem 23



Problem 24

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points of intersection of the radii with the large circle C D E and F, draw *vertical* lines and from the intersection of the radii with the small circle C′, D′, E′, and F′, draw *horizontal* lines intersecting the vertical lines. The intersections of these lines are points on the curve.

As in Problem 19, a free hand curve should be sketched passing through these points. About five points in each quadrant will be sufficient.

PROBLEM 21. **To draw an Ellipse by means of a Trammel.**

As in the two preceding problems, draw the major and minor axes, U V and X Y. Take a slip of paper having a straight edge and mark off C B equal to one-half the major axis, and D B one-half the minor axis. Place the slip of paper in various positions keeping the point D on the major axis and the point C on the minor axis. If this is done the point B will mark various points on the curve. Find as many points as necessary and sketch the curve.

PROBLEM 22. **To draw a Spiral of one turn in a circle.**

Draw a circle with the center at O and a radius of 1½ inches. Mark off on the radius O A, distances of one-eighth inch. As O A is 1½ inches long there will be 12 of these distances. Draw circles through these points. Now draw radii O B, O C, O D etc. each 30 degrees apart (use the 30 degree triangle). This will divide the circle into 12 equal parts. The curve starts at the center O. The next point is the intersection of the line O B and the first circle. The third point is the intersection of O C and the second circle. The fourth point is the intersection of O D and the third circle. Other points are found in the same way. Sketch in pencil the curve passing through these points.

PROBLEM 23. **To draw a Parabola when the Abscissa and Ordinate are given.**

Draw the straight line A B about three inches long. This line is the axis or as it is sometimes called the abscissa. At A and B draw lines perpendicular to A B. Also with the T square draw E C and F D, 1½ inches above and below A B. Let A be the vertex of the parabola. Divide A E into any number of equal parts and divide E C into the same number of equal parts. Through the points of division, R, S, T, U and V, draw horizontal lines and connect L, M, N, O and P, with A. The intersections of the horizontal lines with the oblique lines are points on the curve. For instance, the intersection of A L and the line V is one point and the intersection of A M and the line U is another.

The lower part of the curve A D is drawn in the same manner.

PROBLEM 24. **To draw a Hyperbola when the abscissa E X, the ordinate A E and the diameter X Y are given.**

Draw E F about 3 inches long and mark the point X, 1 inch from E and the point Y, 1 inch from X. With the triangle and T square, draw the rectangles A B D C and O P Q R such that A B is 1 inch in length and A C, 3 inches in length. Divide A E into any number of equal parts and A B into the same number of equal parts. Draw L X, M X and N X; also connect T, U and V with Y. The first point on the curve is the intersection A; the next is the intersection of T Y and L X; the third the intersection of U Y and M X. The remaining points are found in the same manner. The curve X C and the right-hand curve P Y Q are found by repeating the process.

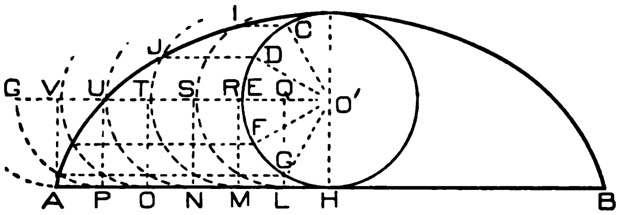
Inking. In inking the figures on this plate, use the French or irregular curve and make full lines for the curves and their axes. The construction lines should be dotted. Ink in all the construction lines used in finding one-half of a curve, and in Problems 19, 20, 23 and 24 leave all construction lines in *pencil* except those inked. In Problems 21 and 22 erase all construction lines not inked. The trammel used in Problem 21 may be drawn in the position as shown, or it may be drawn outside of the ellipse in any convenient place.

The same lettering should be done on this plate as on previous plates.

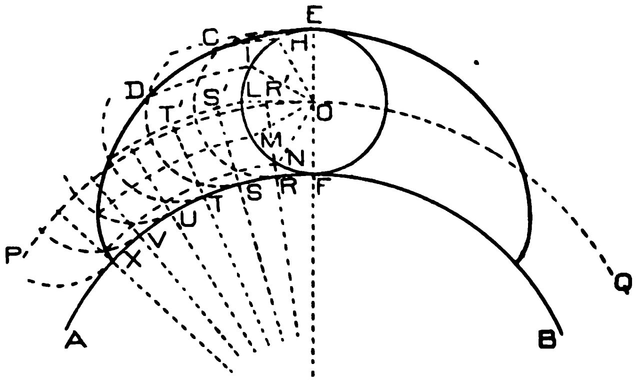
PLATE VIII.

Pencilling. In laying out Plate VIII, draw the border lines and horizontal and vertical center lines as in previous plates, to divide the plate into four spaces for the four problems.

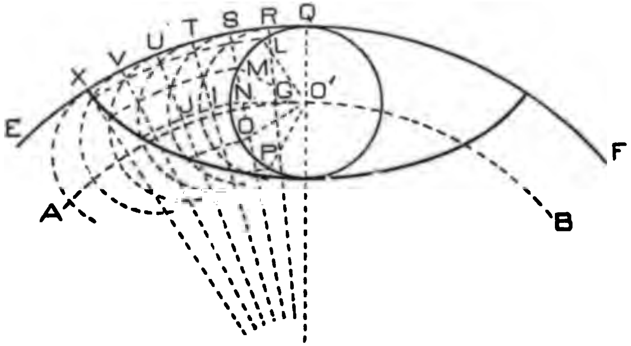
PLATE VIII



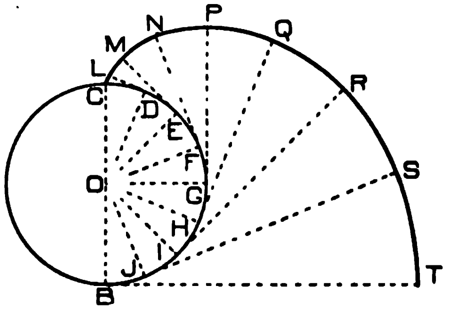
Problem 25



Problem 26



Problem 27



Problem 28

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PROBLEM 25. **To construct a Cycloid when the diameter of the generating circle is given.**

With O′ as a center and a radius of $\frac{7}{8}$ inch draw a circle, and tangent to it draw the indefinite horizontal straight line A B. Divide the circle into any number of equal parts (12 for instance) and through these points of division C, D, E, F, etc., draw horizontal lines. Now with the dividers set so that the distance between the points is equal to the chord of the arc C D, mark off the points L, M, N, O, P on the line A B, commencing at the point H. At these points erect perpendiculars to the center line G O′. This center line is drawn through the point O′ with the T square and is the line of centers of the generating circle as it rolls along the line A B. Now with the intersections Q, R, S, T, etc., of these verticals with the center line as centers describe arcs of circles as shown. The points on the curve are the intersections of these arcs and the horizontal lines drawn through the points C, D, E, F, etc. Thus the intersection of the arc whose center is Q and the horizontal line through C is a point I on the curve. Similarly, the intersection of the arc whose center is R and the horizontal line through D is another point J on the curve. The remaining points, as well as those on the right-hand side, are found in the same manner. To obtain great accuracy in this curve, the circle should be divided into a large number of equal parts, because the greater the number of divisions the less the error due to the difference in length of a chord and its arc.

PROBLEM 26. **To construct an Epicycloid when the diameter of the generating circle and the diameter of the director circle are given.**

The epicycloid and hypocycloid may be drawn in the same manner as the cycloid if arcs of circles are used in place of the horizontal lines. With O as a center and a radius of $\frac{3}{4}$ inch describe a circle. Draw the diameter E F of this circle and produce E F to G such that the line F G is $2\frac{3}{4}$ inches long. With G as a center and a radius of $2\frac{3}{4}$ inches describe the arc A B of the director circle. With the same center G, draw the arc P Q which will be the path of the center of the generating circle as it rolls along the arc A B. Now divide the generating circle into any number of equal parts (twelve for instance) and through the points of division H, I, L, M, and N, draw arcs having G as a center. With the dividers set so that the distance between the points is equal to the chord H I, mark off distances on the director circle A F B. Through these points of division R, S, T, U, etc., draw radii intersecting the arc P Q in the points R′, S′, T′, etc., and with these points as centers describe arcs of circles as in Problem 25. The intersections of these arcs with the arcs already drawn through the points H, I, L, M, etc., are points on the curve. Thus the intersection of the circle whose center is R′ with the arc drawn through the point H is a point upon the curve. Also the arc whose center is S′ with the arc drawn through the point I is another point on the curve. The remaining points are found by repeating this process.

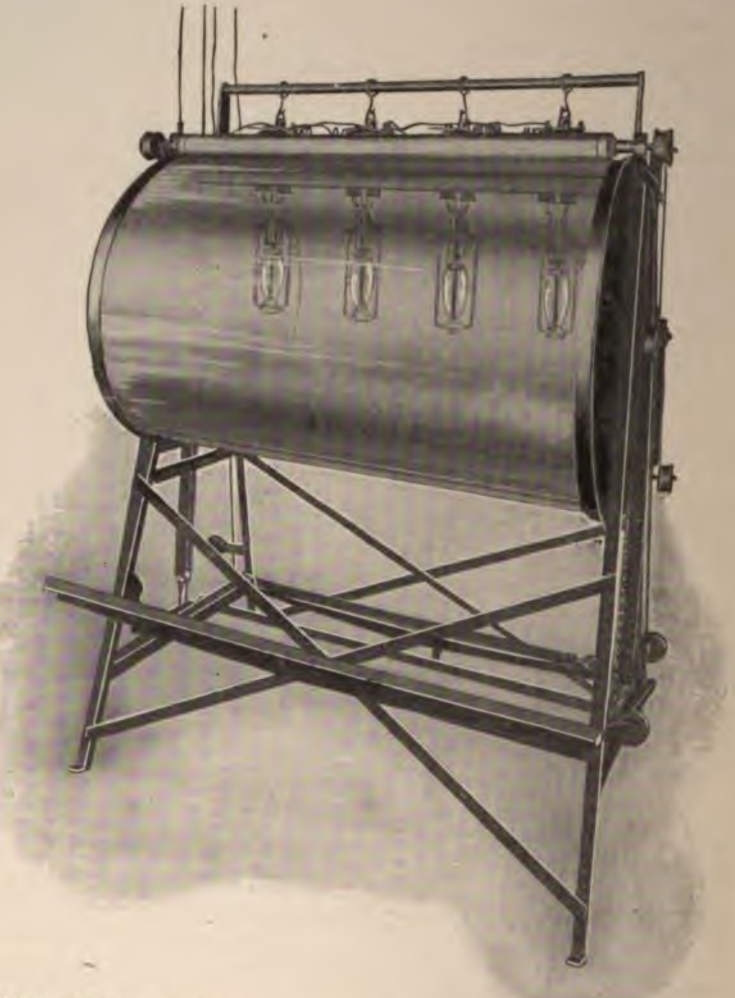
PROBLEM 27. **To draw an Hypocycloid when the diameter of the generating circle and the radius of the director circle are given.**

With O as a center and a radius of 4 inches describe the arc E F, which is the arc of the director circle. Now with the same center and a radius of $3\frac{1}{4}$ inches, describe the arc A B, which is the line of centers of the generating circle as it rolls on the director circle. With O′ as a center and a radius of $\frac{3}{4}$ inch describe the generating circle. As before, divide the generating circle into any number of equal parts (12 for instance) and with these points of division L, M, N, O, etc., draw arcs having O as a center. Upon the arc E F, lay off distances Q R, R S, S T, etc., equal to the chord Q L. Draw radii from the points R, S, T, etc., to the center of the director circle O and describe arcs of circles having a radius equal to the radius of the generating circle, using the points G, I, J, etc., as centers. As in Problem 26, the intersections of the arcs are the points on the curve. By repeating this process, the right-hand portion of the curve may be drawn.

PROBLEM 28. **To draw the Involute of a circle when the diameter of the base circle is known.**

With point O as a center and a radius of 1 inch, describe the base circle. Now divide the circle into any number of equal parts 16 for instance) and connect the points of division with the center of the circle by drawing the radii O C, O D, O E, O F, etc., to O B. At the point D, draw a light pencil line perpendicular to the radius O D. This line will be tangent to the circle. Similarly at the points E, F, G, H, etc., draw tangents to the circle. Now set the dividers so that the distance between the points will be equal to the chord of the arc C D, and measure this distance from D along the tangent. Beginning with the point E, measure on the tangent a distance equal to two of these chords, from the point F measure on the tangent three divisions, and from the point G measure a distance equal to four divisions on the tangent G P. Similarly, measure distances on the remaining tangents, each time adding the length of the chord. This will give the points Q, R, S and T. Now sketch a light pencil line through the points L, M, N, P, etc., to T. This curve will be the involute of the circle.

Inking. The same rules are to be observed in inking *PLATE VIII* as were followed in the previous plates, that is, the curves should be inked in a full line, using the French or irregular curve. All arcs and lines used in locating the points on one-half of the curve should be inked in dotted lines. The arcs and lines used in locating the points of the other half of the curve may be left in pencil in Problems 25 and 26. In Problem 28, all construction lines should be inked. After completing the problems the same lettering should be done on this plate as on previous plates.



CIRCULAR BLUE PRINTING MACHINE, GENERAL ELECTRIC CO.

MECHANICAL DRAWING.

PART III.

PROJECTIONS.

ORTHOGRAPHIC PROJECTION.

Orthographic Projection is the art of representing objects of three dimensions by views on two planes at right angles to each other, in such a way that the forms and positions may be completely determined. The two planes are called planes of projection or co-ordinate planes, one being vertical and the other horizontal, as shown in Fig. 1. These planes are sometimes designated V and H respectively. The intersection of V and H is known as the ground line G L.

The view or projection of the figure on the plane gives the same appearance to the eye placed in a certain position that the object itself does. This position of the eye is at an infinite distance from the plane so that the rays from it to points of a limited object are all perpendicular to the plane. Evidently then the view of a point of the object is on the plane and in the ray through the point and the eye or where this perpendicular to the plane pierces it.

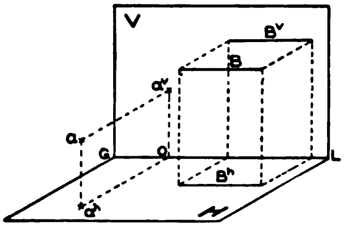


Fig. 1.

Let *a*, Fig. 1, be a point in space, draw a perpendicular from *a* to *V*. Where this line strikes the vertical plane, the projection of *a* is found, namely at a^v. Then drop a perpendicular from *a* to the horizontal plane striking it at a^h, which is the horizontal projection of the point. Drop a perpendicular from a^v to H; this will intersect G L at *o* and be parallel and equal to the line $a\ a^h$. In the same way draw a perpendicular from a^h to V, this also will intersect G L at *o* and will be parallel and equal to $a\ a^v$. In other words, the perpendicular to G L from the projection of a point on either plane equals the distance of the point from the other plane. B in Fig. 1, shows a line in space. B^v is its V projection, and B^h

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its H projection, these being determined by finding views of points at its ends and connecting the points.

Instead of horizontal projection and vertical projection, the terms **plan** and **elevation** are commonly used.

Suppose a cube, one inch on a side, to be placed as in Fig. 2, with the top face horizontal and the front face parallel to the vertical plane. Then the plan will be a one-inch square, and the elevation also a one-inch square. In general the plan is a representation of the top of the object, and the elevation a view of the front. The plan then is a top view, and the elevation a front view.

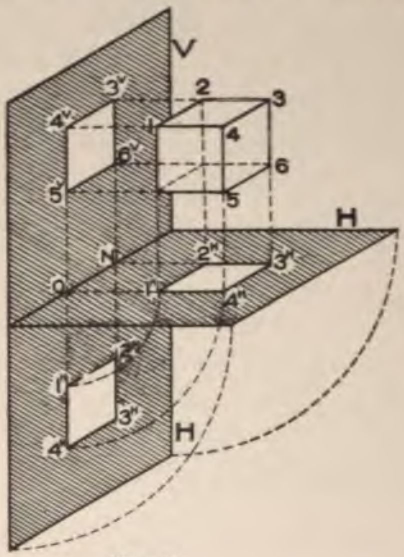


Fig. 2.

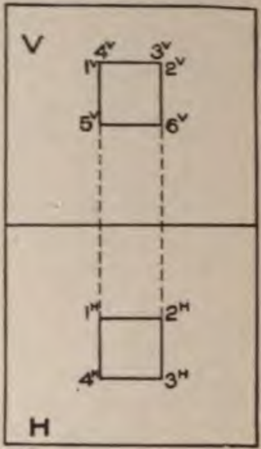


Fig. 3.

Thus far the two planes have been represented at right angles to each other, as they are in space. In order that they may be shown more simply and on the one plane of the paper, H is revolved about G L as an axis until it lies in the same plane as V as shown in Fig. 2. The lines 1^h O and 2^h N, being perpendicular to G L, are in the same straight line as 5^v O and 6^v N, which also are perpendicular to G L. That is—*two views of a point are always in a line perpendicular to G L.* From this it is evident that the plan must be vertically below the elevation, point for point. Now looking directly at the two planes in the revolved position, we get a true orthographic projection of the cube as shown in Fig. 3.

All points on an object at the same height must appear in elevation at the same distance above the ground line. If numbers 1, 2, 3, and 4 on the plan, Fig. 3, indicate the top corners of the cube, then these four points, being at the same height, must be shown in elevation at the same height and at the top, $\frac{4^v}{1^v}$ and $\frac{3^v}{2^v}$. The top of the cube, 1, 2, 3, 4, is shown in elevation as the straight line $\frac{4^v}{1^v}$ - $\frac{3^v}{2^v}$. This illustrates the fact that *if a surface is perpendicular to either plane or projection, its projection on that plane is simply a line; a straight line if the surface is plane, a curved line if the surface is curved.* From the same figure it is seen that the top edge of the cube, 1 4, has for its projection on the vertical plane the point $\frac{4^v}{1^v}$, the principle of which is stated in this way: *If a straight line is perpendicular to either V or H, its projection on that plane is a point, and on the other plane is a line equal in length to the line itself, and perpendicular to the ground line.*

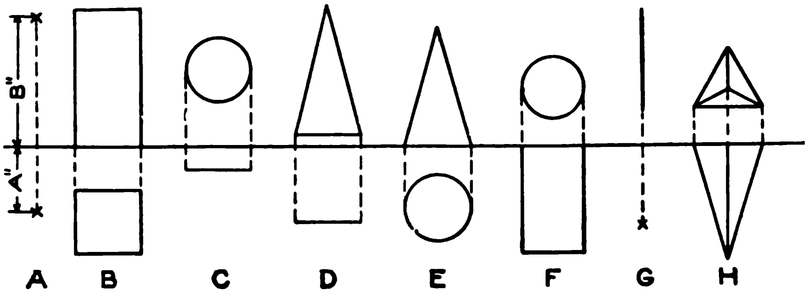


Fig. 4.

Fig. 4 is given as an exercise to help to show clearly the idea of plan and elevation.

A = a point B' above H, and A' in front of V.
B = square prism resting on H, two of its faces parallel to V,
C = circular disc in space parallel to V.
D = triangular card in space parallel to V.
E = cone resting on its base on H.
F = cylinder perpendicular to V, and with one end resting against V.
G = line perpendicular to H.
H = triangular pyramid above H, with its base resting against V.

Suppose in Fig. 5, that it is desired to construct the projections of a prism $1\frac{1}{2}$ in. square, and 2 in. long, standing on one end on the horizontal plane, two of its faces being parallel to the vertical plane. In the first place, as the top end of the prism is a square, the top view or plan will be a square of the same size, that is, $1\frac{1}{2}$ in. Then since the prism is placed parallel to and in front of the vertical plane the plan, $1\frac{1}{2}$ in. square, will have two edges parallel to the ground line. As the front face of the prism is parallel to the vertical plane its projection on V will be a rectangle, equal in length and width to the length and width respectively of the prism, and as the prism stands with its base on H, the elevation, showing height above H, must have its base on the ground line. Observe carefully that points in elevation are vertically over corresponding points in plan.

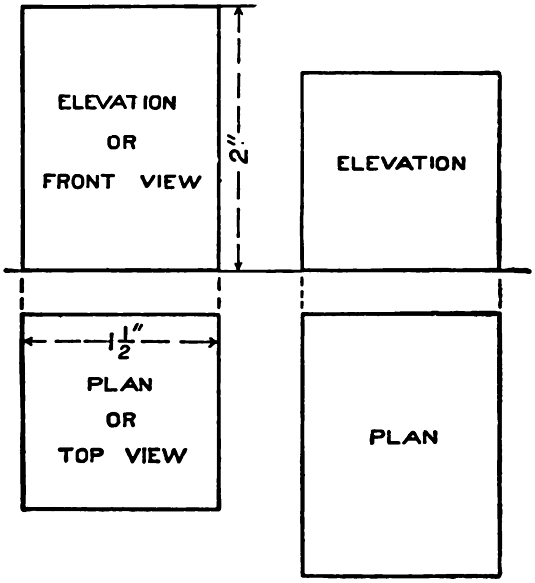
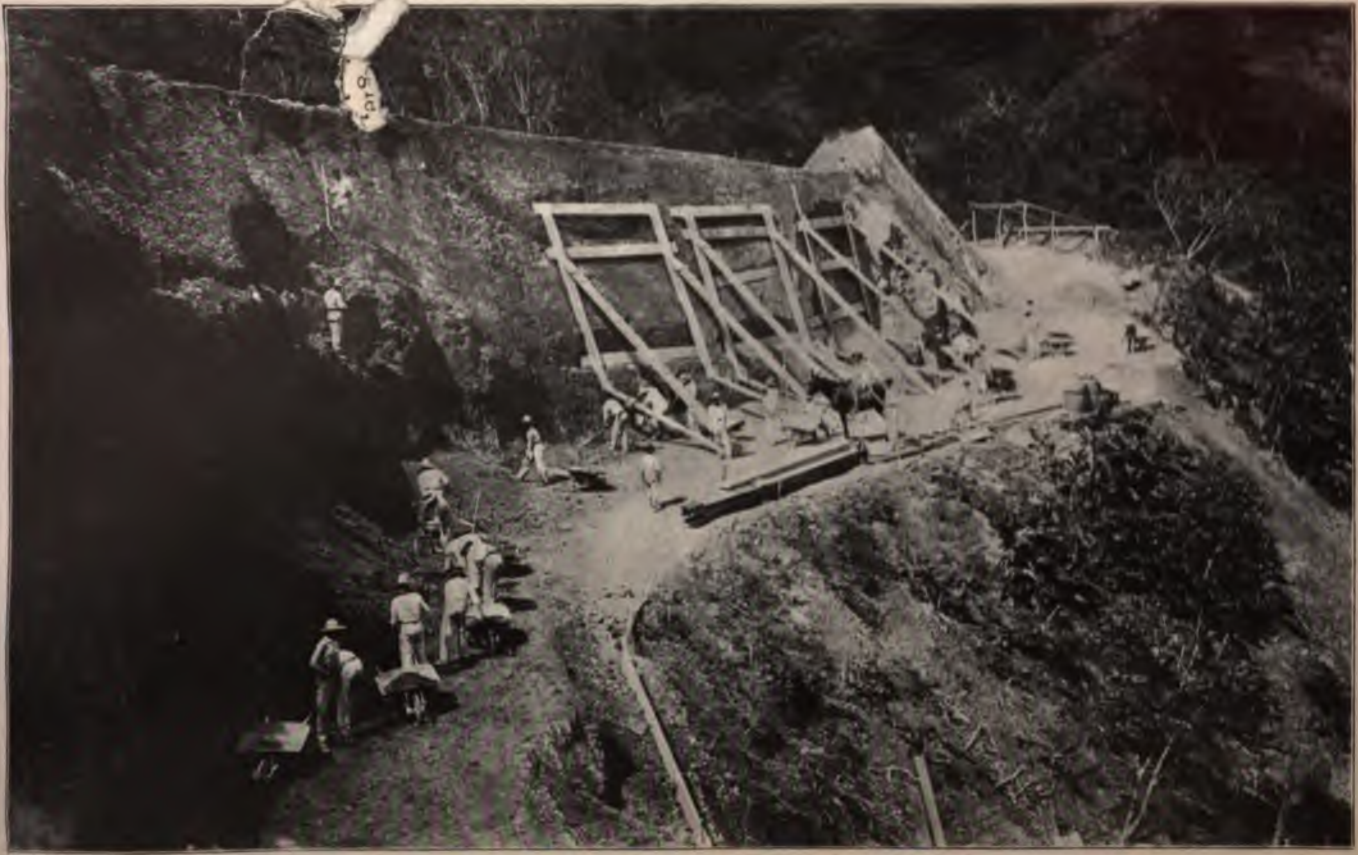


Fig. 5.

The second drawing in Fig. 5 represents a prism of the same size lying on one side on the horizontal plane, and with the ends parallel to V.

The principles which have been used thus far may be stated as follows, —



ROAD-BUILDING IN PORTO RICO

On road from Arecibo to Ponce. Bank shored up, previous to building a retaining wall.

1. If a line or point is on either plane, its other projection must be in the ground line.

2. Height above H is shown in elevation as height above the ground line, and distance in front of the vertical plane is shown in plan as distance from the ground line.

3. If a line is parallel to either plane, its actual length is shown on that plane, and its other projection is parallel to the ground line. A line oblique to either plane has its projection on that plane shorter than the line itself, and its other projection oblique to the ground line. No projection can be longer than the line itself.

4. A plane surface if parallel to either plane, is shown on that plane in its true size and shape; if oblique it is shown smaller than the true size, and if perpendicular it is shown as a straight line. Lines parallel in space must have their V projections parallel to each other and also their H projections.

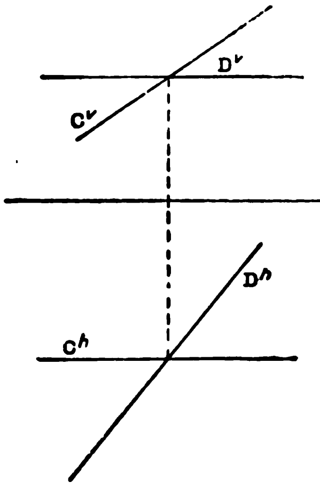


Fig. 6.

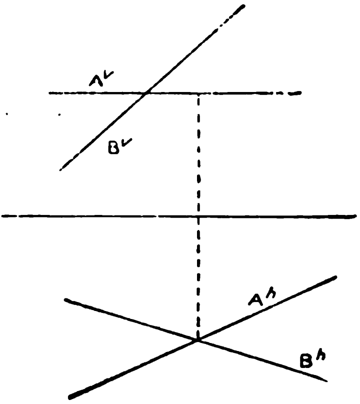


Fig. 7.

If two lines intersect, their projections must cross, since the point of intersection of the lines is a point on both lines, and therefore the projections of this point must be on the projections of both lines, or at their intersection. In order that intersecting lines may be represented, the vertical projections must intersect in a point vertically above the intersection of the horizontal projections. Thus Fig. 6 represents two lines which do intersect as C^v crosses D^v at a point vertically above the intersection of C^h and D^h. In Fig. 7, however, the lines do not intersect since the intersections of their projections do not lie in the same vertical line.

In Fig. 8 is given the plan and elevation of a square pyramid standing on the horizontal plane. The height of the pyramid is the distance A B. The slanting edges of the pyramid, A C, A D, etc., must be all of the same length, since A is directly above the center of the base. What this length is, however, does not appear in either projection, as these edges are not parallel to either V or H.

Suppose that the pyramid be turned around into the dotted position C_1 D_1 E_1 F_1 where the horizontal projections of two of the slanting edges, A C_1 and A E_1 are parallel to the ground line. These two edges, having their horizontal projections parallel to the ground line, are now parallel to V, and therefore their new vertical projections will show their true lengths. The base of the pyramid is still on H, and therefore is projected on V in the ground line. The apex is in the same place as before, hence the vertical projection of the pyramid in its new position is shown by the dotted lines. The vertical projection A C_1^v is the true length of edge A C. Now if we wish to find simply the true length of A C, it is unnecessary to turn the whole pyramid around, as the one line A C will be sufficient.

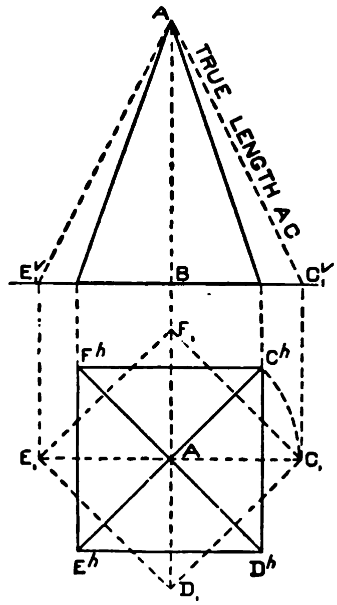
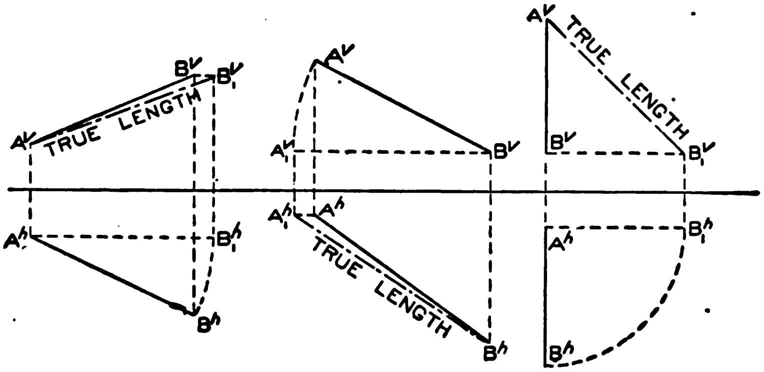


Fig. 8.

The principle of finding the true length of lines is this, and can be applied to any case: Swing one projection of the line parallel to the ground line, using one end as center. On the other projection the moving end remains at the same distance from the ground line, and of course vertically above or below the same end in its parallel position. This new projection of the line shows its true length. See the three Figures at the top of page 9.

Third plane of projection or profile plane. A plane perpendicular to both co-ordinate planes, and hence to the ground line, is called a *profile plane.* This plane is vertical in position, and may be used as a plane of projection. A projection on the profile plane is called a profile view, or *end view*, or sometimes edge view, and is often required in machine or other drawing when the plan and elevation do not sufficiently give the shape and dimensions.



A projection on this plane is found in the same way as on the V plane, that is, by perpendiculars drawn from points on the object.

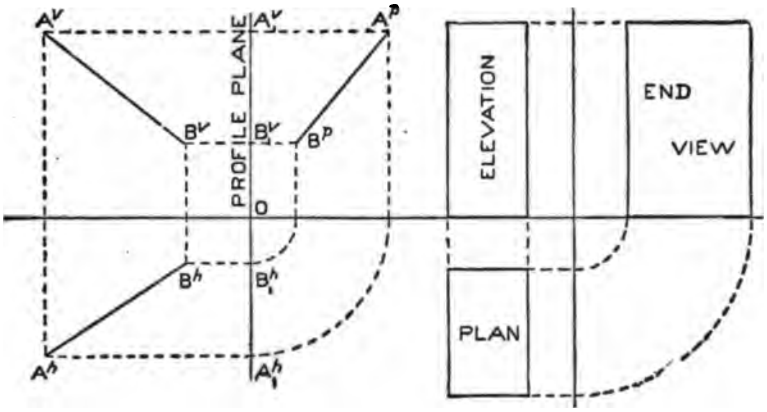


Fig. 9.

Since, however, the profile plane is perpendicular to the ground line. it will be seen from the front and top simply as a straight line; in order that the size and shape of the profile view may be shown, the profile plane is revolved into V using its intersection with the vertical plane as the axis.

Given in Fig. 9, the line A B by its two projections A^v B^v and A^h B^h, and given also the profile plane. Now by projecting the line on the profile by perpendiculars, the points A_1^v B_1^v and B_1^h A_1^h are found. Revolving the profile plane like a door on its hinges, all points in the plane will move in horizontal circles, so the horizontal projections A_1^h and B_1^h will move in arcs of circles with O as center to the ground line, and the vertical projections B_1^v and A_1^v will move in lines parallel to the ground line to positions directly above the revolved points in the ground line, giving the profile view of the line A^p B^p. Heights, it will be seen, are the same in profile view as in elevation. By referring to the rectangular prism in the same figure, we see that the elevation gives vertical dimensions and those parallel to V, while the end view shows vertical dimensions and those perpendicular to V. The profile view of any object may be found as shown for the line A B by taking one point at a time.

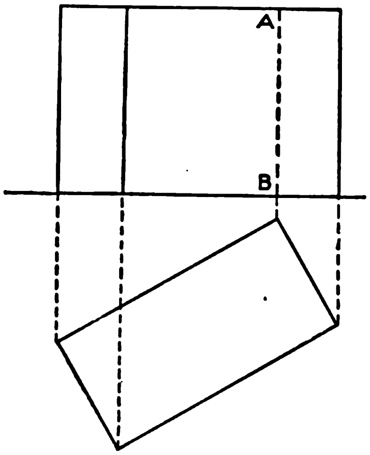


Fig. 10.

In Fig. 10 there is represented a rectangular prism or block, whose length is twice the width. The elevation shows its height. As the prism is placed at an angle, three of the vertical edges will be visible, the fourth one being invisible.

In mechanical drawing lines or edges which are invisible are drawn *dotted.* The edges which in projection form a part of the outline or contour of the figure must always be visible, hence always *full lines.* The plan shows what lines are visible in elevation, and the elevation determines what are visible in plan. In Fig. 10, the plan shows that the dotted edge A B is the back edge, and in Fig. 11, the dotted edge C D is found, by looking at the elevation, to be the lower edge of the triangular prism. In general, if in elevation an edge projected *within* the figure is a back edge, it must be dotted, and in plan if an edge projected within the outline is a lower edge it is dotted.

Fig. 12 is a circular cylinder with the length vertical and with a hole part way through as shown in elevation. Fig. 13 is plan, elevation and end view of a triangular prism with a square hole from end to end. The plan and elevation alone would be insufficient to determine positively the shape of the hole, but the end view shows at a glance that it is square.

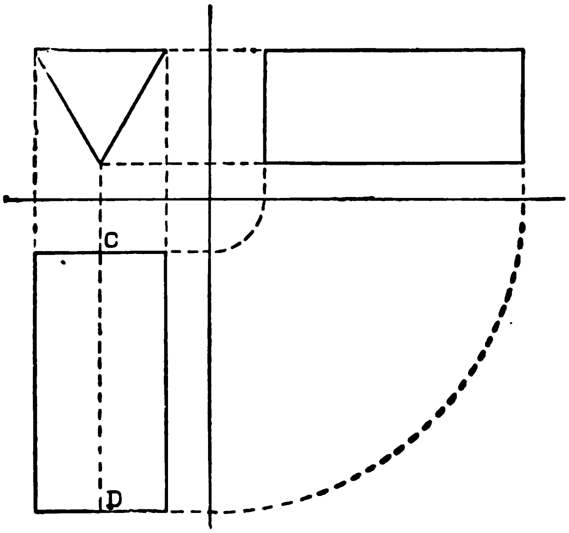


Fig. 11.

In Fig. 14 is shown plan and elevation of the frustum of a square pyramid, placed with its base on the horizontal plane. If the frustum is turned through 30°, as shown in the plan of Fig. 15, the top view or plan must still be the same shape and size, and as the frustum has not been raised or lowered, the heights of all points must appear the same in elevation as before in Fig. 14. The elevation is easily found by projecting points up from the plan, and projecting the height of the top horizontally across from the first elevation, because the height does not change.

The same principle is further illustrated in Figs. 16 and 17. The elevation of Fig. 16 shows a square prism resting on one edge, and raised up at an angle of 30° on the right-hand side. The plan gives the width or thickness, $\frac{5}{8}$ in. Notice that the length of the plan is greater than 2 in. and that varying the angle at

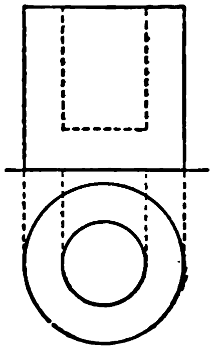


Fig. 12.

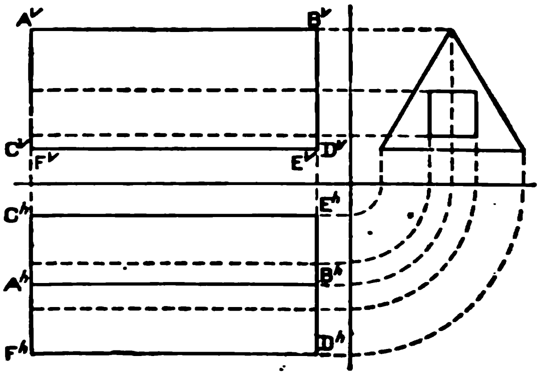


Fig. 13.

which the prism is slanted would change the length of the plan. Now if the prism be turned around through any angle with the vertical plane, the lower edge still being on H, and the inclination

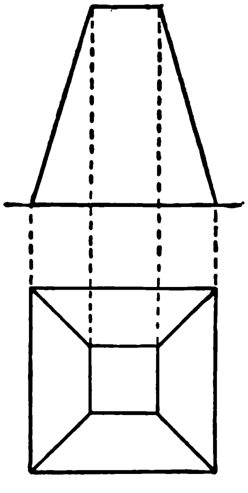


Fig. 14.

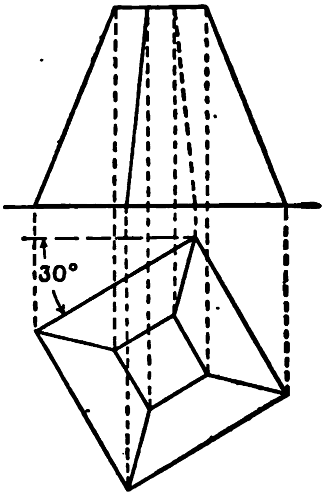


Fig. 15.

of 30° with H remaining the same, the plan must remain the same size and shape.

If the angle through which the prism be turned is 45°, we have the second plan, exactly the same shape and size as the first. The elevation is found by projecting the corners of the prism vertically up to the heights of the same points in the first elevation. All the other points are found in the same way as point No. 1.

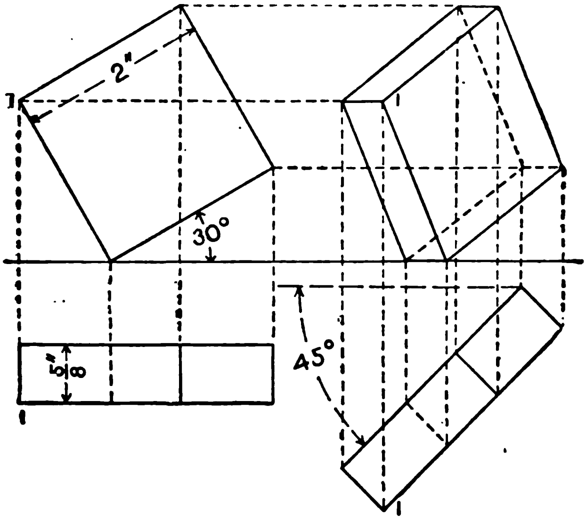


Fig. 16.

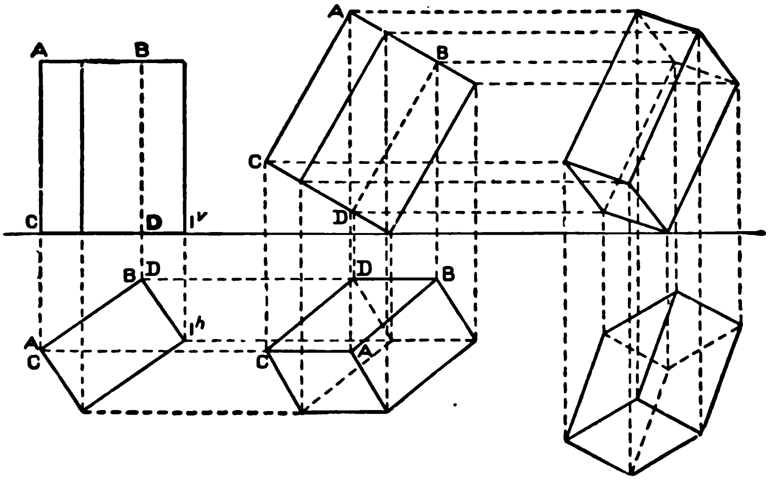


Fig. 17.

Three positions of a rectangular prism are shown in Fig. 17. In the first view, the prism stands on its base, its axis therefore is parallel to the vertical plane. In the second position, the axis is still parallel to V and one corner of the base is on the horizontal plane. The prism has been turned as if on the line 1^h 1^v as an axis, so that the inclination of all the faces of the prism to the vertical plane remains the same as before. That is, if in the first figure the side A B C D makes an angle of 30° with the vertical, the same side in the second position still makes 30° with the vertical plane. Hence the elevation of No. 2 is the same shape and size as in the first case. The plan is found by projecting the corners down from the elevation to meet horizontal lines projected across from the corresponding points in the first plan. The third position shows the prism with all its faces and edges making the same angles with the horizontal as in the second position, but with the plan at a different angle with the ground line. The plan then is the same shape and size as in No. 2, and the elevation is found by projecting up to the same heights as shown in the preceeding elevation. This principle may be applied to any solid, whether bounded by plane surfaces or curved.

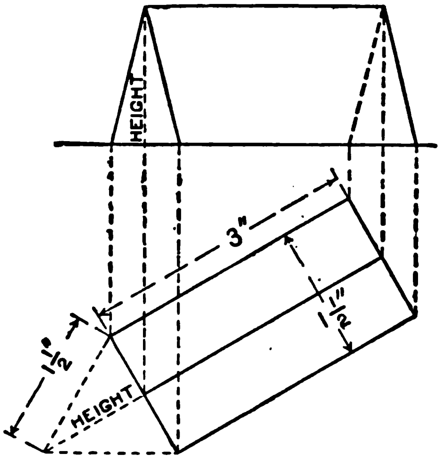


Fig. 18.

This principle as far as it relates to heights, is the same that was used for profile views. An end view is sometimes necessary before the plan or elevation of an object can be drawn. Suppose that in Fig. 18 we wish to draw the plan and elevation of a triangular prism 3″ long, the end of which is an equilateral triangle

$1\frac{1}{2}''$ on each side. The prism is lying on one of its three faces on H, and inclined toward the vertical plane at an angle of 30°. We are able to draw the plan at once, because the width will be $1\frac{1}{2}$ inches, and the top edge will be projected half way between the other two. The length of the prism will also be shown. Before we can draw the elevation, we must find the height of the top edge. This height, however, must be equal to the altitude of the triangle forming the end of the prism. All that is necessary, then, is to construct an equilateral triangle $1\frac{1}{2}''$ on each side, and measure its altitude.

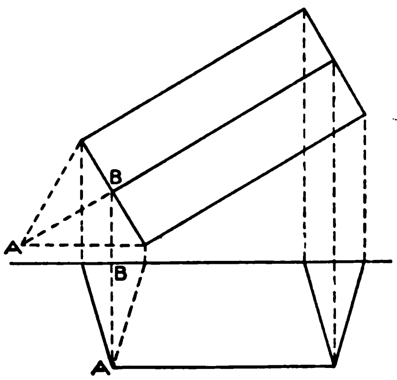


Fig. 18.

A very convenient way to do this is shown in the figure by laying one end of the prism down on H. A similar construction is shown in Fig. 19, but with one face of the prism on V instead of on H.

In all the work thus far the plan has been drawn below and the elevation above. This order is sometimes inverted and the plan put above the elevation, but the plan still remains a top view no matter where placed, so that after some practice it makes but little difference to the draughtsman which method is employed.

SHADE LINES.

It is often the case in machine drawing that certain lines or edges are made heavier than others. These heavy lines are called shade lines, and are used to improve the appearance of the drawing, and also to make clearer in some cases the shape of the object. The shade lines are not put on at random, but according to some system. Several systems are in use, but only that one which seems most consistent will be described. The shade lines are lines or edges separating light faces from dark ones, assuming the light always to come in a direction parallel to the dotted diagonal of the cube shown in Fig. 20. The direction of the light, then, may be represented on H by a line at 45° running backward to the right and on V by a 45° line sloping downward and to the right. Considering the cube in Fig. 20, if the light comes in the direction indicated, it is evident that the front, left-hand side and top will be light, and the bottom, back and right-hand side dark. On the plan, then, the shade lines will be the back edge 1 2 and the right-hand edge 2 3, because these edges are between light faces and dark ones. On the elevation, since the front is light, and the right-hand side and bottom dark, the edges 3 7 and 8 7 are shaded. As the direction of the light is represented on the plan by 45° lines and on the elevation also by 45° lines,

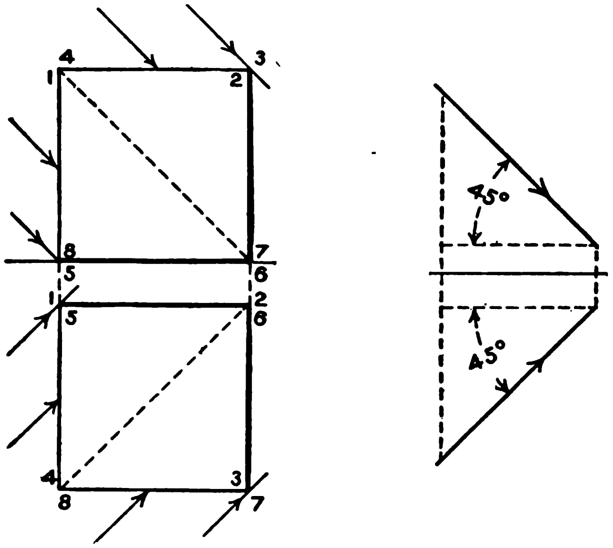


Fig. 20.

we may use the 45° triangle with the T-square to determine the light and dark surfaces, and hence the shade lines. If the object stands on the horizontal plane, the 45° triangle is used on the plan, as shown in Fig. 21, but if the length is perpendicular to the vertical plane, the 45° triangle is used on the elevation, as shown in Fig. 22. This is another way of saying that the 45° triangle is used on that projection of the object which shows the end. By applying the triangle in this way we determine the light and dark surfaces, and then put the shade lines between them. Dotted lines, however, are never shaded, so if a line which is between a light and a dark surface is invisible it is not shaded. In Fig. 21 the plan shows the end of the solid, hence the 45° triangle is used in the direction indicated by the arrows:

This shows that the light strikes the left-hand face, but not the back or the right-hand. The top is known to be light without the triangle, as the light comes downward, so the shade edges on the plan are the back and right-hand. On the elevation two faces of the prism are visible; one is light, the other dark, hence the edge between is shaded. The left-hand edge, being between a light face and a dark one is a shade line. The right-hand face is dark, the top of the prism is light, hence the upper edge of this face is a shade line. The right-hand edge is not shaded, because by referring to the plan, it is seen to be between two dark surfaces. In shading a cylinder or a cone the same rule is followed, the only difference being that as the surface is curved, the light is tangent, so an element instead of an edge marks the separation of the dark from the light, and is *not* shaded. The elements of a cylinder or cone should *never* be shaded, but the bases may. In Fig. 23, Nos. 3 and 4, the student should carefully notice the difference between the shading of the cone and cylinder.

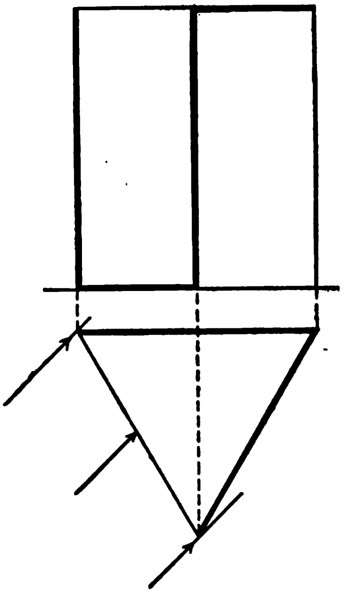


Fig. 21.

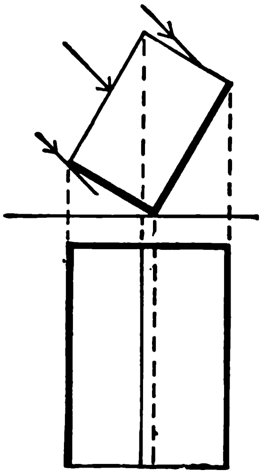


Fig. 22.

If in No. 4 the cone were inverted, the opposite half of the base would be shaded, for then the base would be light, whereas it is now dark. In Nos. 7 and 8 the shade lines of a cylinder and a circular hole are contrasted.

In No. 7 it is clear that the light would strike inside on the further side of the hole, commencing half way where the 45° lines are tangent. The other half of the inner surface would be dark, hence the position of the shade line. The shade line then enables us to tell at a glance whether a circle represents a hub or boss, or depression or hole. Fig. 24 represents plan, elevation and profile view of a square prism. Here as before, the view showing the end is the one used to determine the light and dark surfaces, and then the shade lines put in accordingly.

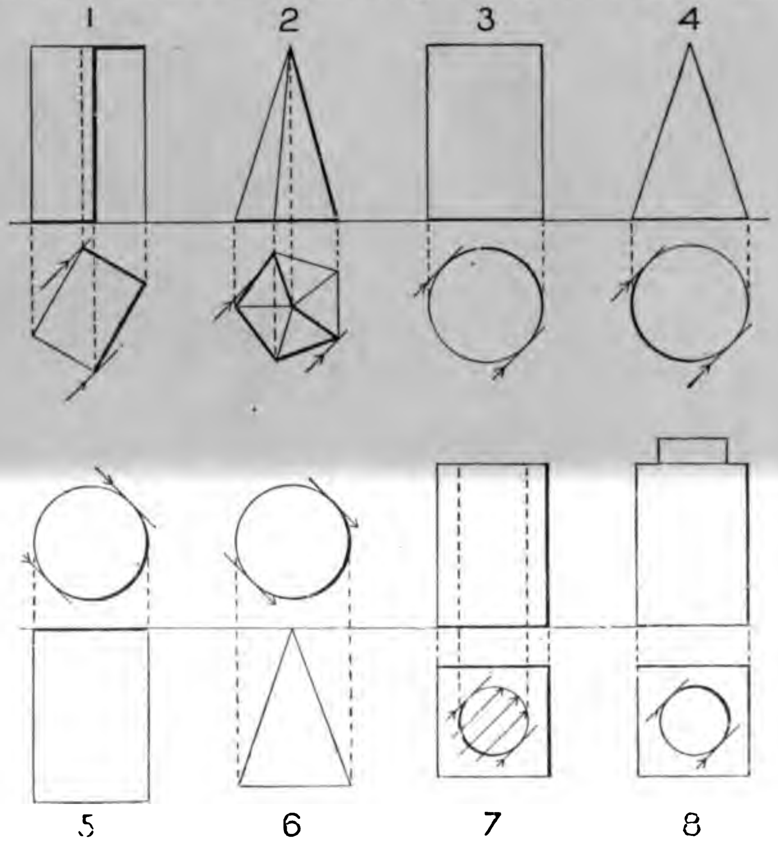


Fig. 23.

In putting on the shade lines, the extra width of line is put *inside* the figure, not outside. In shading circles, the shade line is made of varying width, as shown in the figures. The method of obtaining this effect by the compass is to keep the same radius, but to change the center slightly in a direction parallel to the rays of light, as shown at A and B in No. 2 of Fig. 24.

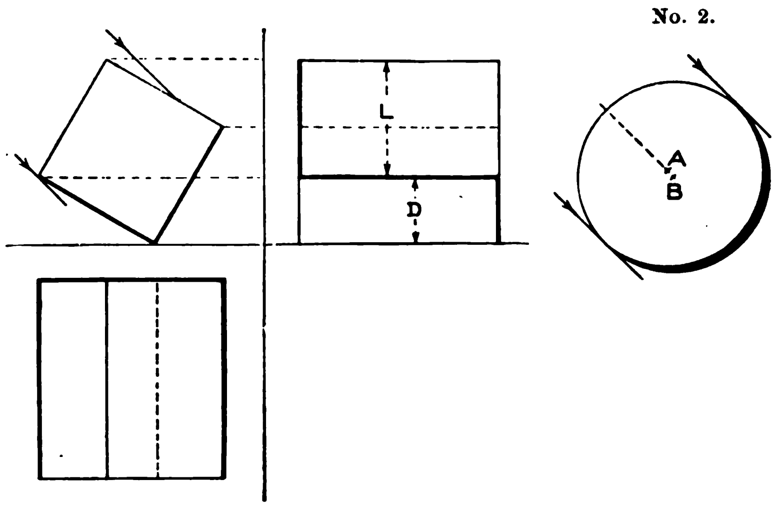


Fig. 24.

INTERSECTION AND DEVELOPMENT.

If one surface meets another at some angle, an intersection is produced. Either surface may be plane, or curved. If both are plane, the intersection is a straight line; if one is curved, the intersection is a curve, except in a few special cases; and if both are curved, the intersection is usually curved.

In the latter case, the entire curve does not always lie in the same planes. If all points of any curve lie in the same plane, it is called a plane curve. A plane intersecting a curved surface must always give either a plane curve or a straight line.

In Fig. 25 a square pyramid is cut by a plane A parallel to the horizontal. This plane cuts from the pyramid a four-sided figure, the four corners of which will be the points where A cuts the four slanting edges of the solid. The plane intersects edge *o b* at point 4^v in elevation. This point must be found in plan vertically below on the horizontal projection of line *o b*, that is, at point 4^h. Edge *o e* is directly in front of *o b*, so is shown in elevation as the same line, and plane A intersects *o e* at point 1^v in elevation, found in plan at 1^h. Points 3 and 2 are obtained in the same way. The intersection is shown in plan as the square 1 2 3 4, which is also its true size as it is parallel to the horizontal plane. In a similar way the sections are found in Figs. 26 and 27. It will be seen that in these three cases where the planes are parallel to the bases, the sections are of the same shape as the bases, and have their sides parallel to the edges of the bases.

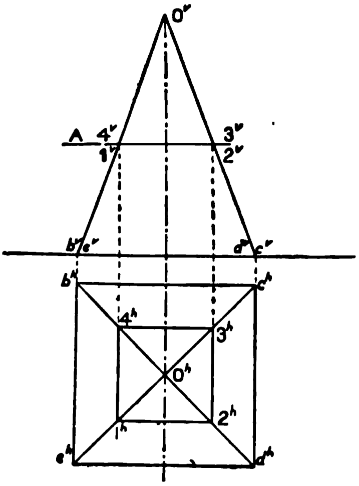


Fig. 25.

It is an invariable rule that when such a solid is cut by a plane parallel to its base, the section is a figure of the same shape as the base. If then in Fig. 28 a right cone is intersected by a plane parallel to the base the section must be a circle, the center of which in plan coincides with the apex. The radius must equal *o d*.

In Figs. 29 and 30 the cutting plane is not parallel to the base, hence the intersection will not be of the same shape as the base. The sections are found, however, in exactly the same manner as in the previous figures, by projecting the points where the plane intersects the edges in elevation on to the other view of the same line.

INTERSECTION OF PLANES WITH CONES OR CYLINDERS.

Sections cut by a plane from a cone have already been defined as *conic sections*. These sections may be either of the following: two straight lines, circle, ellipse, parabola, hyperbola. All except the parabola and hyperbola may also be cut from a cylinder.

Methods have previously been given for constructing the

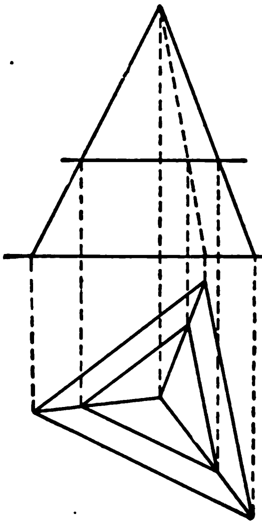


Fig. 26.

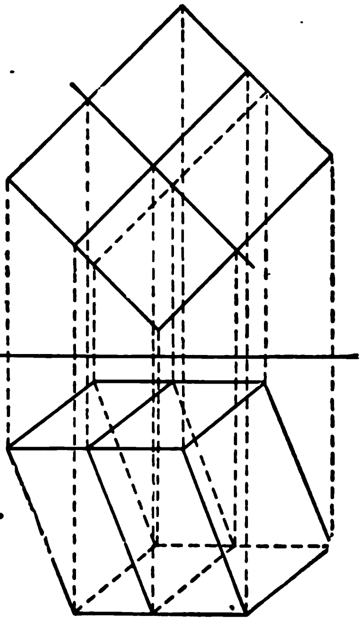


Fig. 27.

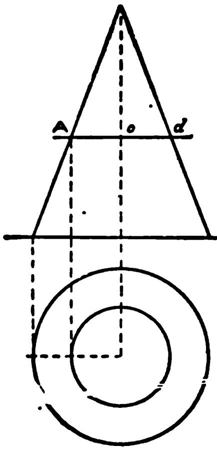


Fig. 28.

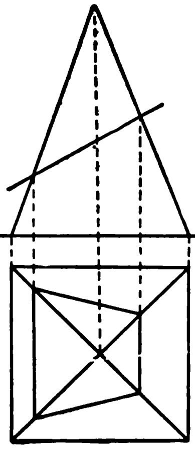


Fig. 29.

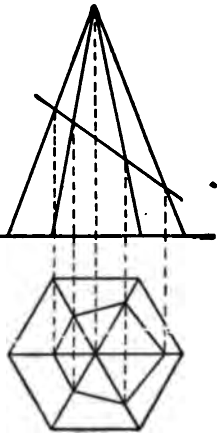


Fig. 30.

ellipse, parabola and hyperbola without projections; it will now be shown that they may be obtained as actual intersections.

In Fig. 31 the plane cuts the cone obliquely. To find points on the curve in plan take a series of horizontal planes

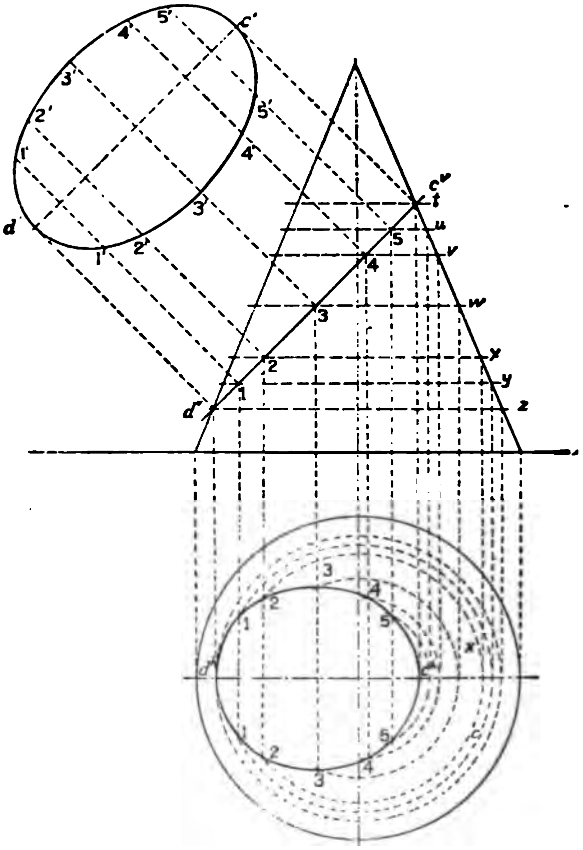
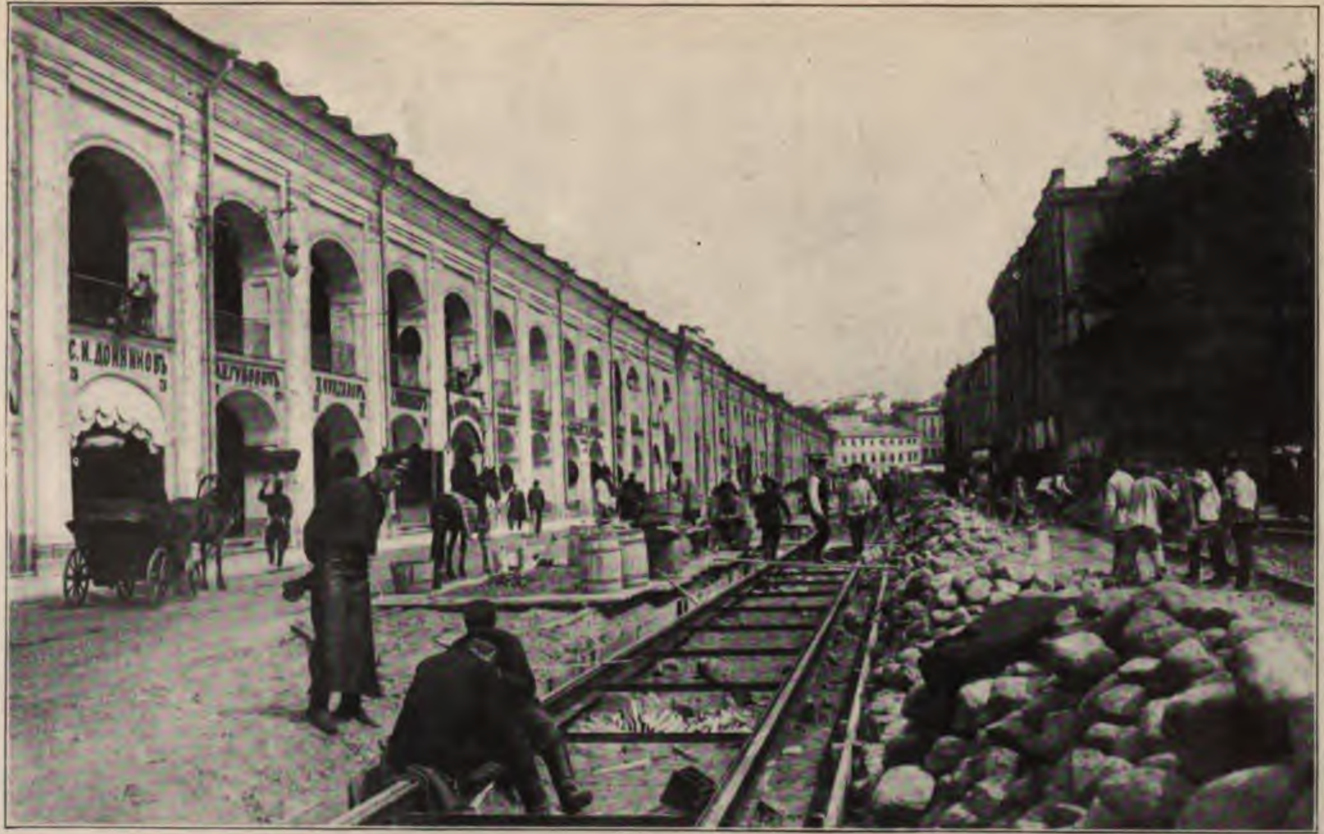


Fig. 31

x y z etc., between points c^v and d^v. One of these planes, as *w*, should be taken through the center of *c d*. The points *c* and *d* must be points on the curve, since the plane cuts the two contour elements at these points. The horizontal projections of the contour elements will be found in a horizontal line passing through the center of the base; hence the horizontal projection of *c* and *d* will be found on this center line, and will be the extreme ends of the curve. Contour elements are those forming the outline.



STREET IN ST. PETERSBURG TORN UP FOR THE LAYING OF TRACK FOR A NEW STREET-CAR LINE

THE NEW
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The plane x cuts the surface of the cone in a circle, as it is parallel to the base, and the diameter of the circle is the distance between the points where x crosses the two contour elements. This circle, lettered x on the plan, has its center at the horizontal projection of the apex. The circle x and the curve cut by the plane are both on the surface of the cone, and their vertical projections intersect at the point 2. Also the circle x and the curve must cross twice, once on the front of the cone and once on the back. Point 2 then represents two points which are shown in plan directly beneath on the circle x, and are points on the required intersection. Planes y and z, and as many more as may be necessary to determine the curve accurately, are used in the same way. The curve found is an ellipse. The student will readily see that the true size of this ellipse is not shown in the plan, for the plane containing the curve is not parallel to the horizontal.

In order to find the **actual size** of the ellipse, it is necessary to place its plane in a position parallel either to the vertical or to the horizontal. The actual length of the long diameter of the ellipse must be shown in elevation, $c^v\,d^v$, because the line is parallel to the vertical plane. The plane of the ellipse then may be revolved about $c^v\,d^v$ as an axis until it becomes parallel to V, when its true size will be shown. For the sake of clearness of construction, $c^v\,d^v$ is imagined moved over to the position $c'\,d'$, parallel to $c^v\,d^v$. The lines 1—1, 2—2, 3—3 on the plan show the true width of the ellipse, as these lines are parallel to H, but are projected closer together than their actual distances. In elevation these lines are shown as the points 1, 2, 3. at their true distance apart. Hence if the ellipse is revolved around its axis $c^v\,d^v$, the distances 1—1, 2—2, 3—3 will appear perpendicular to $c^v\,d^v$, and the true size of the figure be shown. This construction is made on the left, where $1'$—$1'$, $2'$—$2'$ and $3'$—$3'$ are equal in length to 1—1, 2—2, 3—3 on the plan.

In Fig. 32 a plane cuts a cylinder obliquely. This is a simpler case, as the horizontal projection of the curve coincides with the base of the cylinder. To obtain the true size of the section, which is an ellipse, any number of points are assumed on the plan and projected up on the cutting plane, at 1, 2, 3, etc.

The lines drawn through these points perpendicular to 1 7 are made equal in length to the corresponding distances 2'—2', 3'—3' etc., on the plan, because 2'—2' is the true width of curve at 2.

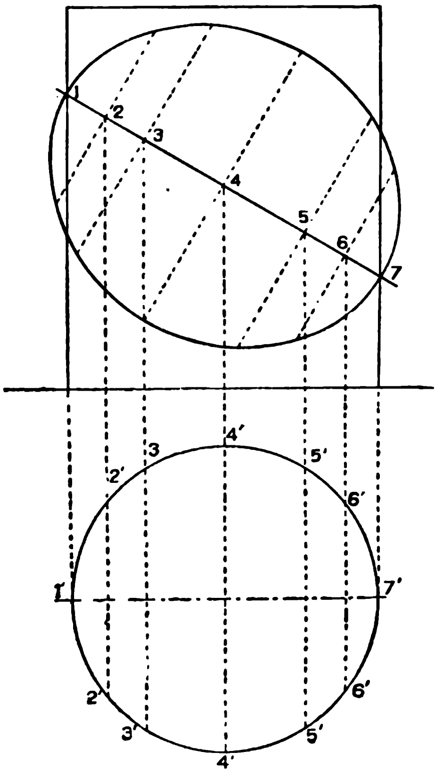

Fig. 32.

If a cone is intersected by a plane which is parallel to only one of the elements, as in Fig. 33, the resulting curve is the parabola, the construction of which is exactly similar to that for the ellipse as given in Fig. 31. If the intersecting plane is parallel to more than one element, or is parallel to the axis of the cone, a hyperbola is produced.

In Fig. 34, the vertical plane A is parallel to the axis of the cone. In this instance the curve when found will appear in its true size, as plane A is parallel to the vertical. Observe that the highest point of the curve is found by drawing the circle X on the plan tangent to the given plane. One of the points where this circle crosses the diameter is projected up to the contour element of the cone, and the horizontal plane X drawn. Intermediate planes Y, Z, etc., are chosen, and corresponding circles drawn in plan. The points where these circles are crossed by the plane A are points on the curve, and these points are projected up to the elevation on the planes Y, Z, etc.

DEVELOPMENTS.

The development of a surface is the true size and shape ot the surface extended or spread out on a plane. If the surface to be developed is of such a character that it may be flattened out without tearing or folding, we obtain an exact development, as in case of a cone or cylinder, prism or pyramid. If this cannot be done, as with the sphere, the development is only approximate.

In order to find the development of the rectangular prism in Fig 35, the back face, 1 2 7 6, is supposed to be placed in contact with some plane, then the prism turned on the edge 2 7 until the side 2 3 8 7 is in contact with the same plane, then this continued until all four faces have been placed on the same plane. The rectangles 1 4 3 2 and 6 7 8 5 are for the top and bottom respectively. The development then is the exact size and shape of a covering for the prism. If a rectangular hole is cut through the prism, the openings in the front and back faces will be shown in the development in the centers of the two broad faces.

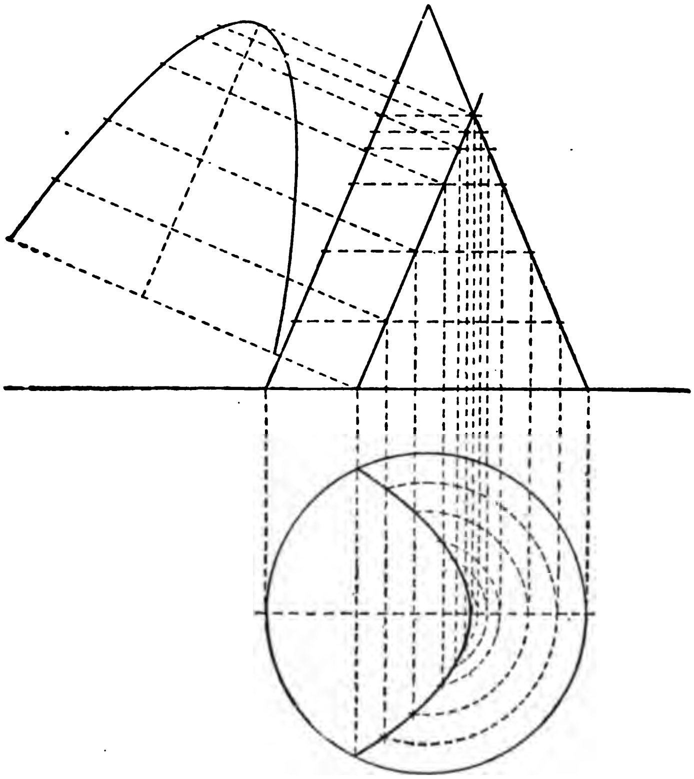

Fig. 33.

The development of a right prism. then, consists of as many rectangles joined together as the prism has sides, these rectangles being the exact size of the faces of the prism, and in addition two polygons the exact size of the bases. It will be found helpful in developing a solid to number or letter all of the corners on the projections, then designate each face when developed in the same way as in the figure.

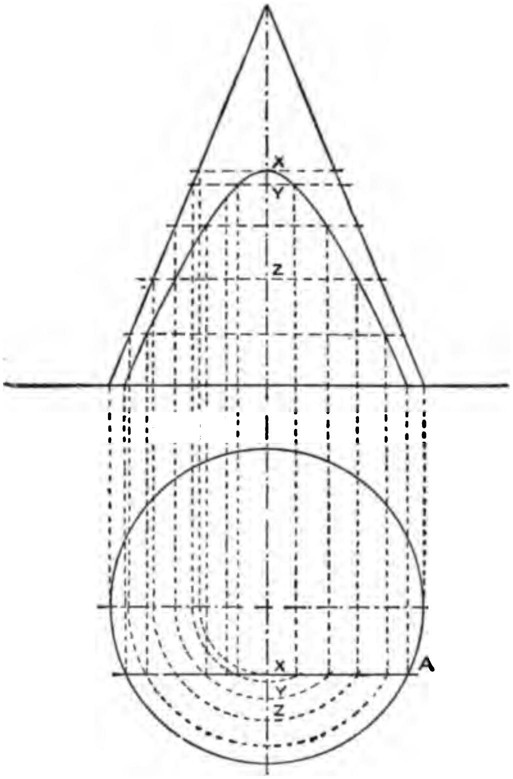

Fig. 34.

If a cone be placed on its side on a plane surface, one element will rest on the surface. If now the cone be rolled on the plane, the vertex remaining stationary, until the same element is in contact again, the space rolled over will represent the development of the convex surface of the cone. A, Fig. 36, is a cone cut by a plane parallel to the base. In B, let the vertex of the cone be placed at V, and one element of the cone coincide with V A I. The length of this element is taken from the elevation A, of either contour element. All of the elements of the cone are of the same length, so when the cone is rolled each point of the base as it touches the plane will be at the same distance from the vertex. From this it follows that the development of the base will be the arc of a circle of radius equal to the length of an element. To find the length of this arc which is equal to the distance around the base, divide the plan of the circumference of the base into any number of equal parts, as twelve, then with the length of one of these parts as radius, lay off twelve spaces, 1....13, join 1 and 13 with V, and the sector is the development of the cone from vertex to base. To represent on the development the circle cut by the section plane, take as radius the length of the element from the vertex to D, and with V as center describe an arc. The development of the frustum of the cone will be the portion of the circular ring. This of course does not include the

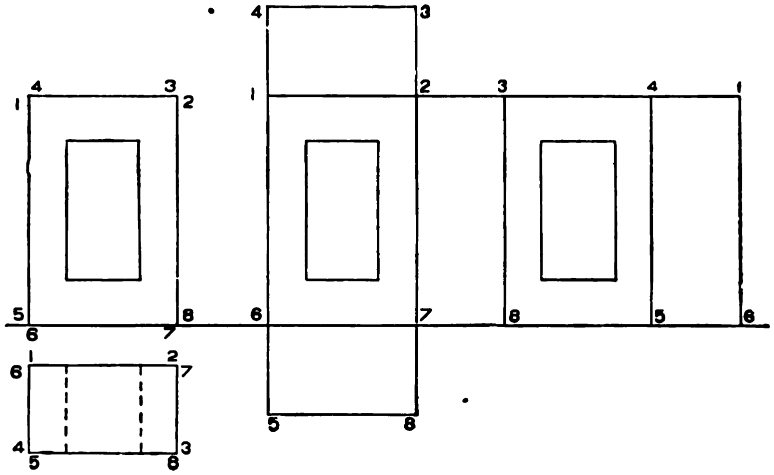

Fig. 35.

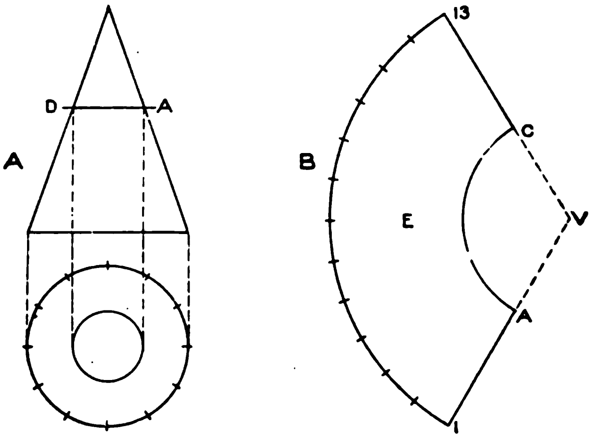

Fig. 36.

development of the bases, which would be simply two circles the same sizes as shown in plan.

A and B, Fig. 37, represent the plan and elevation of a regular triangular pyramid and its development. If face C is placed on the plane its true size will be shown at C in the development. The true length of the base of triangle C is shown in the plan. The slanting edges, however, not being parallel to the vertical, are not shown in elevation in their true length. It becomes necessary then, to find the true length of one of these edges as shown in Fig. 6, after which the triangle may be drawn in its full size at C in the development. As the pyramid is regular, three equal triangles as shown developed at C, D and E, together with the base F, constitute the development.

If a right circular cylinder is to be developed, or rolled upon a plane, the elements, being parallel, will appear as parallel lines, and the base, being perpendicular to the elements, will develop as a straight line perpendicular to the elements. The width of the development will be the distance around the cylinder, or the circumference of the base. The base of the cylinder in Fig. 38, is divided into twelve equal parts, 1 2 3, etc. Commencing at point 1 on the development these twelve equal spaces are laid along the straight line, giving the development of the base of the cylinder, and the total width. To find the development of the curve cut by the oblique plane, draw in elevation the elements corresponding to the various divisions of the base, and note the points

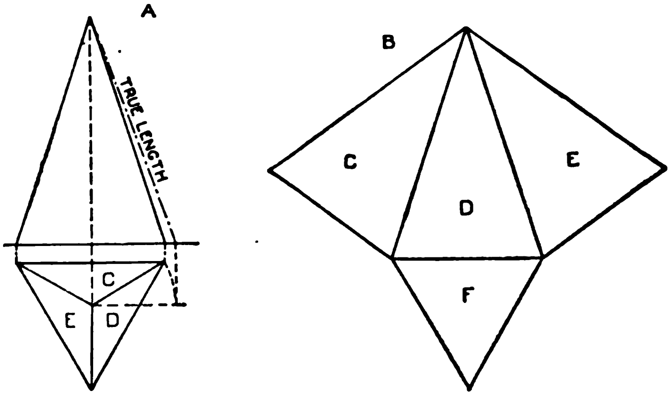

Fig. 37.

where they intersect the oblique plane. As we roll the cylinder beginning at point 1, the successive elements 1, 12, 11, etc., will appear at equal distances apart, and equal in length to the lengths of the same elements in elevation. Thus point number 10 on the development of the curve is found by projecting horizontally across from 10 in elevation. It will be seen that the curve is symmetrical, the half on the left of 7 being similar to that on the right. The development of any curve whatever on the surface of the cylinder may be found in the same manner.

The principle of cylinder development is used in laying out elbow joints, pipe ends cut off obliquely, etc. In Fig. 39 is shown plan and elevation of a three-piece elbow and collar, and developments of the four pieces. In order to construct the various parts making up the joint, it is necessary to know what shape and size must be marked out on the flat sheet metal so that when cut out and rolled up the three pieces will form cylinders with the ends fitting together as required. Knowing the kind of elbow desired, we first draw the plan and elevation, and from these make the developments. Let the lengths of the three pieces A, B and C be the same on the upper outside contour of the elbow, the piece B at an angle of 45°; the joint between A and B bisects the angle between the two lengths, and in the same way the joint between B and C. The lengths A and C will then be the same,

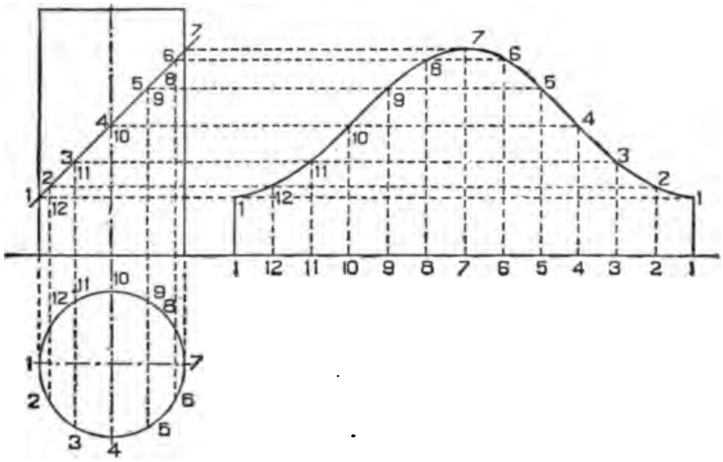

Fig. 38.

and one pattern will answer for both. The development of A is made exactly as just explained for Fig. 38, and this is also the development of C.

It should be borne in mind that in developing a cylinder we must always have a base at right angles to the elements, and if the cylinder as given does not have such a base, it becomes necessary to cut the cylinder by a plane perpendicular to the elements, and use the intersection as a base. This point must be clearly understood in order to proceed intelligently. A section at right angles to the elements is the only section which will unroll in a straight line, and is therefore the section from which we must work in developing other sections. As B has neither end at right angles to its length, the plane X is drawn at the middle and perpendicular to the length. B is the same diameter pipe as C and A, so the section cut by X will be a circle of the same diameter as the base of A, and its development is shown at X.

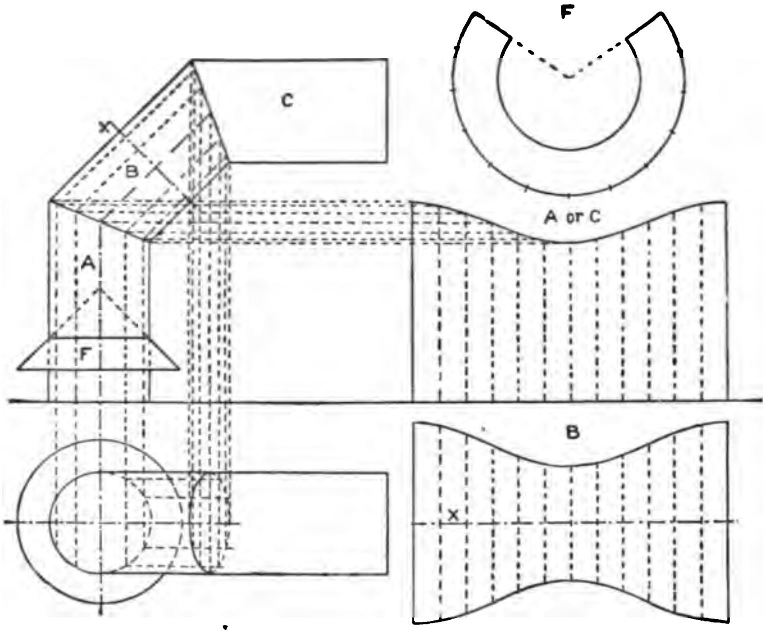

Fig. 39.

From the points where the elements drawn on the elevation of A meet the joint between A and B, elements are drawn on B, which are equally spaced around B the same as on A. The spaces then laid off along X are the same as given on the plan of A. Commencing with the left-hand element in B, the length of the upper element between X and the top corner of the elbow is laid off above X, giving the first point in the development of the end of B fitting with C. The lengths of the other elements in the elevation of B are measured in the same way and laid off from X. The development of the other end of the piece B is laid off below X, using the same distances, since X is half way between the ends. The development of the collar is simply the development of the frustum of a cone, which has already been explained, Fig. 86. The joint between B and C is shown in plan as an ellipse, the construction of which the student should be able to understand from a study of the figure.

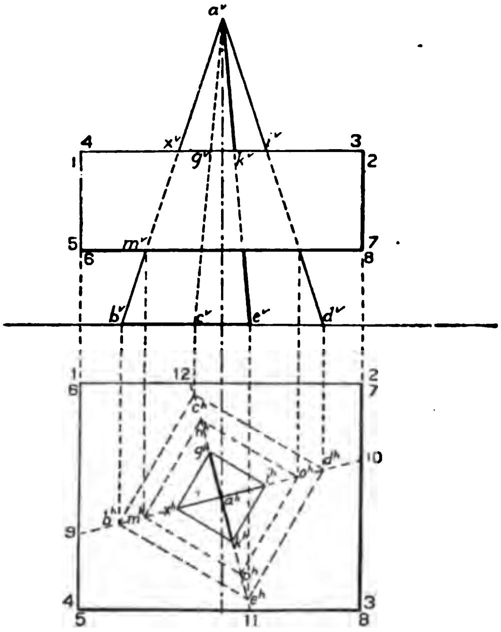

Fig. 40.

The intersection of a rectangular prism and pyramid is shown in Fig. 40. The base *b c d e* of the pyramid is shown dotted in plan, as it is hidden by the prism. All four edges of the pyramid pass through the top of the prism, 1, 2, 3, 4. As the top of the prism is a horizontal plane, the edges of the pyramid are shown passing through the top in elevation at $x^v g^v k^v i^v$. These four points might be projected to the plan on the four edges of the pyramid; but it is unnecessary to project more than one, since the general principle applies here that if a cone, pyramid, prism or cylinder be cut by a plane parallel to the base, the section is a figure parallel and similar to the base. The one point x^v is therefore projected down to *a b* in plan, giving x^h, and with this as one corner, the square $x^h g^h i^h k^h$ is drawn, its sides parallel to the edges of the base. This square is the intersection of the pyramid with the top of the prism.

The intersection of the pyramid with the bottom of the prism is found in like manner, by taking the point where one edge of the pyramid as $a\ b$ passes through the bottom of the prism shown in elevation as point m^v, projecting down to m^h on $a^h b^h$, and drawing the square $m^h n^h o^h p^h$ parallel to the base of the pyramid. These two squares constitute the entire intersection of the two solids, the pyramid going through the bottom and coming out at the top of the prism. As much of the slanting edges of the pyramid as are above the prism will be seen in plan, appearing as the diagonals of the small square, and the rest of the pyramid, being below the top surface of the prism, will be dotted in plan.

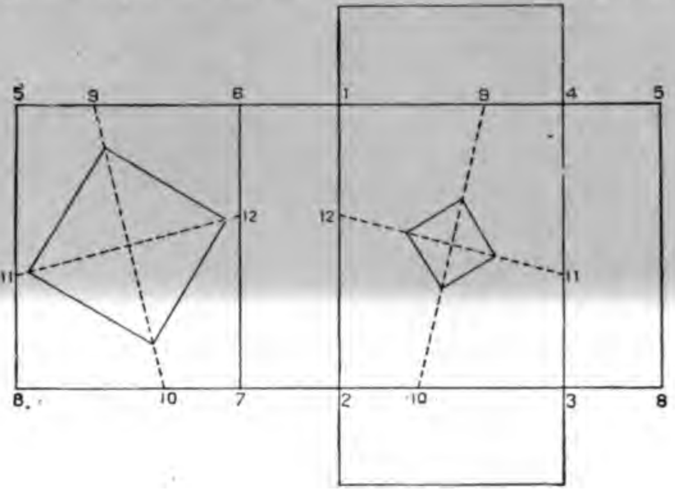

Fig. 41.

Fig. 41 is the development of the rectangular prism, showing the openings in the top and bottom surfaces through which the pyramid passed. The development of the top and bottom, back and front faces will be four rectangles joined together, the same sizes as the respective faces. Commencing with the bottom face 5 6 7 8, next would come the back face 6 1 2 7, then the top, etc. The rectangles at the ends of the top face 1 2 3 4 are the ends of the prism. These might have been joined on any other face as well. Now find the development of the square in the bottom 5 6 7 8. As the size will be the same as in projection, it only remains to determine its position. This position, however, will have the same relation to the sides of the rectangle as in the plan. The center of the square in this case is in the center of the face. To transfer the diagonals of the square to the development, extend them in plan to intersect the edges of the prism in points 9, 10, 11 and 12. Take the distance from 5 to 9 along the edge 5 6, and lay it on the development from 5 along 5 6, giving point 9. Point 10 located in the same way and connected with 9, gives the position of one diagonal. The other diagonal is obtained in a similar way, then the square constructed on these diagonals. The same method is used for locating the small square on the top face.

If the intersection of a cylinder and prism is to be found, we may either obtain the points where elements of the cylinder pierce the prism, or where edges and lines parallel to edges on the surface of the prism cut the cylinder.

A series of parallel planes may also be taken cutting curves from the cylinder and straight lines from the prism; the intersections give points on the intersection of the two solids.

Fig. 42 represents a triangular prism intersecting a cylinder. The axis of the prism is parallel to V and inclined to H. Starting with the size and shape of the base, this is laid off at a_1 b^h c^h, and the altitude of the triangle taken and laid off at a^v c^v in elevation, making right angles with the inclination of the axis to H. The plan of the prism is then constructed. To find the intersection of the two solids, lines are drawn on the surface of the prism parallel to the length and the points where these lines and the edges pierce the cylinder are obtained and joined, giving the curve.

The top edge of the prism goes into the top of the cylinder. This point will be shown in elevation, since the top of the cylinder is a plane parallel to H and perpendicular to V, and therefore projected on V as a straight line. The upper edge, then, is found to pass into the top of the cylinder at point o, o^v and o^h. The intersection of the two upper faces of the prism with the top of the cylinder will be straight lines drawn from point o and will be shown in plan. If we can find where another line of the surface o a h 14 pierces the upper base of the cylinder, this point joined with *o* will determine the intersection of this face with the top of the cylinder. A surface may always be produced, if necessary, to find an intersection.

Edge *a b* pierces the plane of the top of the cylinder at point

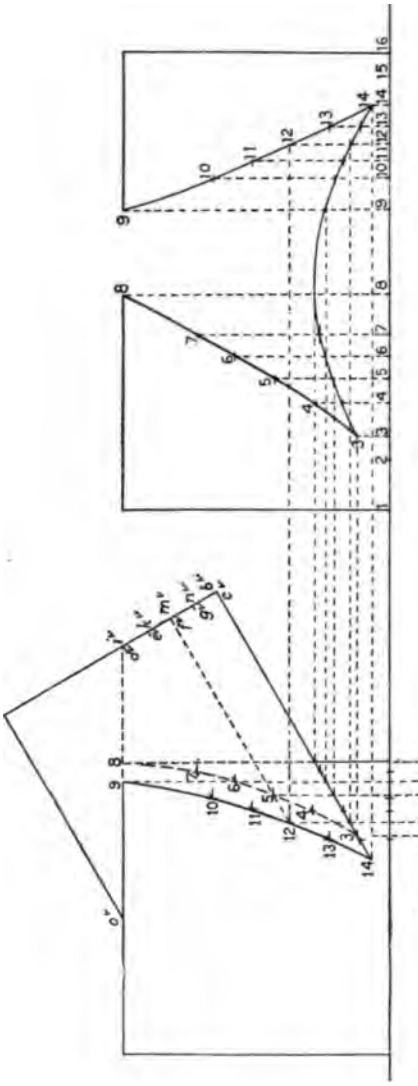

Fig. 43.

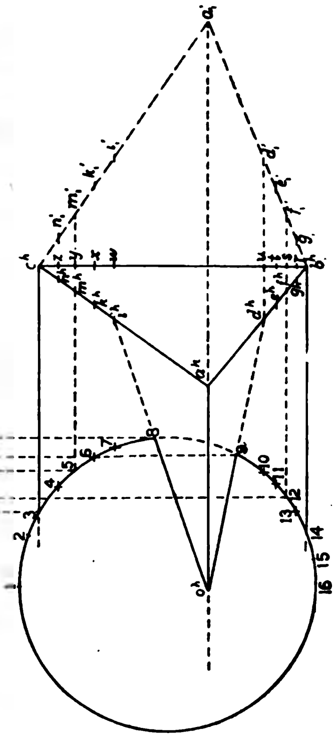

Fig. 42.

d, seen in elevation; therefore the line joining this point with *o* is the intersection of one upper face of the prism with the upper base of the cylinder. The only part of this line needed, of course, is within the actual limits of the base, that is *o* 9. The intersection *o* 8 of the other top face is found by tne same method. On the convex surface of the cylinder there will be three curves, one for each face of the prism. Points 8 and 9 on the upper base of the cylinder, will be where the curves for the two upper faces will begin. The point *d* is found on the revolved position of the base at d_1, and d_1 *b* is divided into the equal parts $d_1 - e_1$, $e_1 - f_1$, etc., which revolve back to d^h, e^h, f^h and g^h. The divisions are made equal merely for convenience in developing. The vertical projections of *d*, *e*, etc., are found on the vertical projection of *a b*, directly above d^h, e^h, etc., or may be found by taking from the revolved position of the base, the perpendiculars from d_1 e_1 etc., to c^h b^h and laying them off in elevation from b^v along b^v a^v. Lines such as *f* 12, *m* 5, etc., parallel to *a o* are drawn in plan and elevation. Points i^h k^h m^h n^h are taken directly behind d^h e^h f^h g^h hence their vertical projections coincide. Points n_1 m_1 k_1 and i_1 are formed by projecting across from n^h m^h k^h and i^h.

The convex surface of the cylinder is perpendicular to H, so the points where the lines on the prism pierce it will be projected on plan as the points where these lines cross the circle, 14, 13, 12, 11.......3. The vertical projections of these points are found on the corresponding lines in elevation, and the curves drawn through. The curve 3, 4....8 must be dotted, as it is on the back of the cylinder. The under face of the prism, which ends with the line *b c*, is perpendicular to the vertical plane, so the curve of intersection will be projected on V as a straight line. Point 14 is one end of this curve. 3 the other end, and the curve is projected in elevation as the straight line from 14 to the point where the lower edge of the prism crosses the contour element of the cylinder.

Fig. 43 gives the development of the right-hand half of the cylinder, beginning with number 1. As previously explained, the distance between the elements is shown in the plan, as 1—2, 2—3. 3—4 and so on. These spaces are laid off in the development along a straight line representing the development of the base, and from these points the elements are drawn perpendicularly.

The lengths of the elements in the development from the base to the curve are exactly the same as on the elevation, as the elevation gives the true lengths. If then the development of the base is laid off along the same straight line as the vertical projection of the base, the points in elevation may be projected across with the T-square to the corresponding elements in the development. The points on the curve cut by the under face of the prism are on the same elements as the other curves, and their vertical projections are on the under edge of the prism, hence these points are projected across for the development of the lower curve.

In Fig. 44 is given the development of the prism from the right-hand end as far as the intersection with the cylinder, beginning at the left with the top edge *a o*, the straight line ***a b c a*** being the development of the base. As this must be the actual distance around the base, the length is taken from the true size of the base, a_1 b^h c^h. The parallel lines drawn on the surfaces of the prism must appear on the development their true distances apart, hence the distances a_1 d_1, d_1 e_1, etc., are made equal to *a d*, *d e*, etc. on the development. The actual distances between the parallel lines on the bottom face of the prism are shown along the edge of the base, b^h c^h. Perpendicular lines are drawn from the points of division on the development.

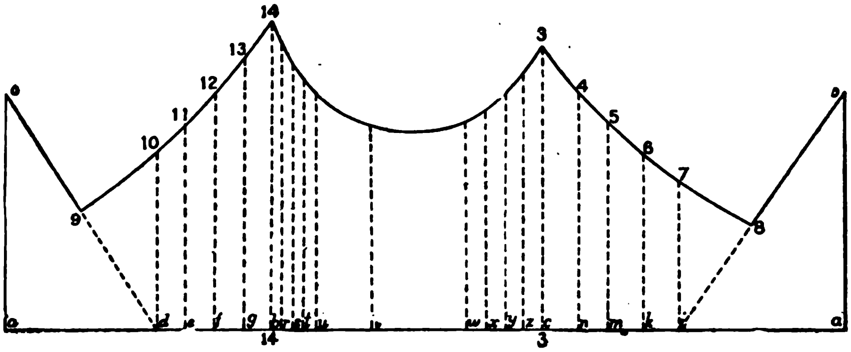

Fig. 44.

The position of the developed curve is found by laying off the true lengths on the perpendiculars. These true lengths (of the parallel lines) are not shown in plan, as the lines are not parallel to the horizontal plane, but are found in elevation. The length ***oa*** **on the development** is equal to a^v o^v, ***d*** **10 to** d^v **10, and** so on for all the rest. Point 9 is found as follows: on the projections, the straight line from *o* to *d* passes through point 9, and the true distance from *o* to 9 is shown in plan. All that is necessary, then, is to connect *o* and *d* on the development, and lay off from *o* the distance o^h9. Number 8 is found in the same way.

ISOMETRIC PROJECTION.

Heretofore an object has been represented by two or more projections. Another system, called **isometrical drawing,** is used to show in one view the three dimensions of an object, length (or height), breadth, and thickness. An isometrical drawing of an object, as a cube, is called for brevity the "isometric" of the cube.

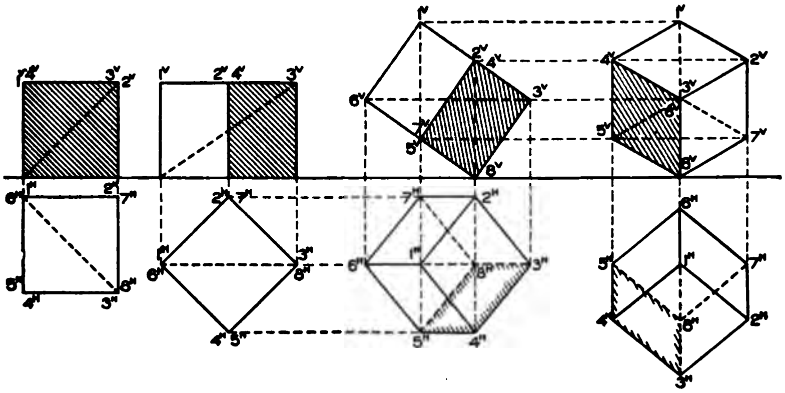

Fig. 45.

To obtain a view which shows the three dimensions in such a way that measurements can be taken from them, draw the cube in the simple position shown at the left of Fig. 45, in which it rests on H with two faces parallel to V; the diagonal from the front upper right-hand corner to the back lower left-hand corner is indicated by the dotted line. Swing the cube around until the diagonal is parallel with V as shown in the second position. Here the front face is at the right. In the third position the lower end of the diagonal has been raised so that it is parallel to H, becoming thus parallel to both planes. The plan is found by the principles of projection, from the elevation and the preceding plan. The front face is now the lower of the two faces shown in the elevation. From this position the cube is swung around, using the corner resting on the H as a pivot, until the diagonal is perpendicular to V but still parallel to H. The plan remains the same, except as regards position; while the elevation, obtained by projecting across from the previous elevation, gives the isometrical projection of the cube. The front face is now at the left.

In the last position, as one diagonal is perpendicular to V, it follows that all the faces of the cube make equal angles with V, hence are projected on that plane as equal parallelograms. For the same reason all the edges of the cube are projected in elevation in equal lengths, but, being inclined to V, appear shorter than they actually are on the object. Since they are all equally foreshortened and since a drawing may be made at any scale, it is customary to make all the isometrical lines of a drawing full length. This will give the same proportions, and is much the simplest method. Herein lies the distinction between an isometrical projection and an isometric drawing.

It will be noticed that the figure can be inscribed in a circle, and that the outline is a perfect hexagon. Hence the lines showing breadth and length are 30° lines, while those showing height are vertical.

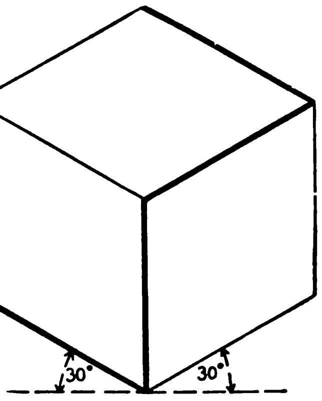

Fig. 46.

Fig. 46 shows the isometric of a cube, 1 inch square. All of the edges are shown in their true length, hence all the surfaces appear of the same size. In the figure the edges of the base are inclined at 30° with a T-square line, but this is not always the case. For rectangular objects, such as prisms, cubes, etc., the base edges are at 30° only when the prism or cube is supposed to be in the simplest possible position. The cube in Fig. 46 is supposed to be in the position indicated by plan and elevation in Fig. 47, that is, standing on its base, with two faces parallel to the vertical plane.

If the isometric of the cube in the position of Fig. 48 were required, it could not be drawn with the base edges at 30°; neither

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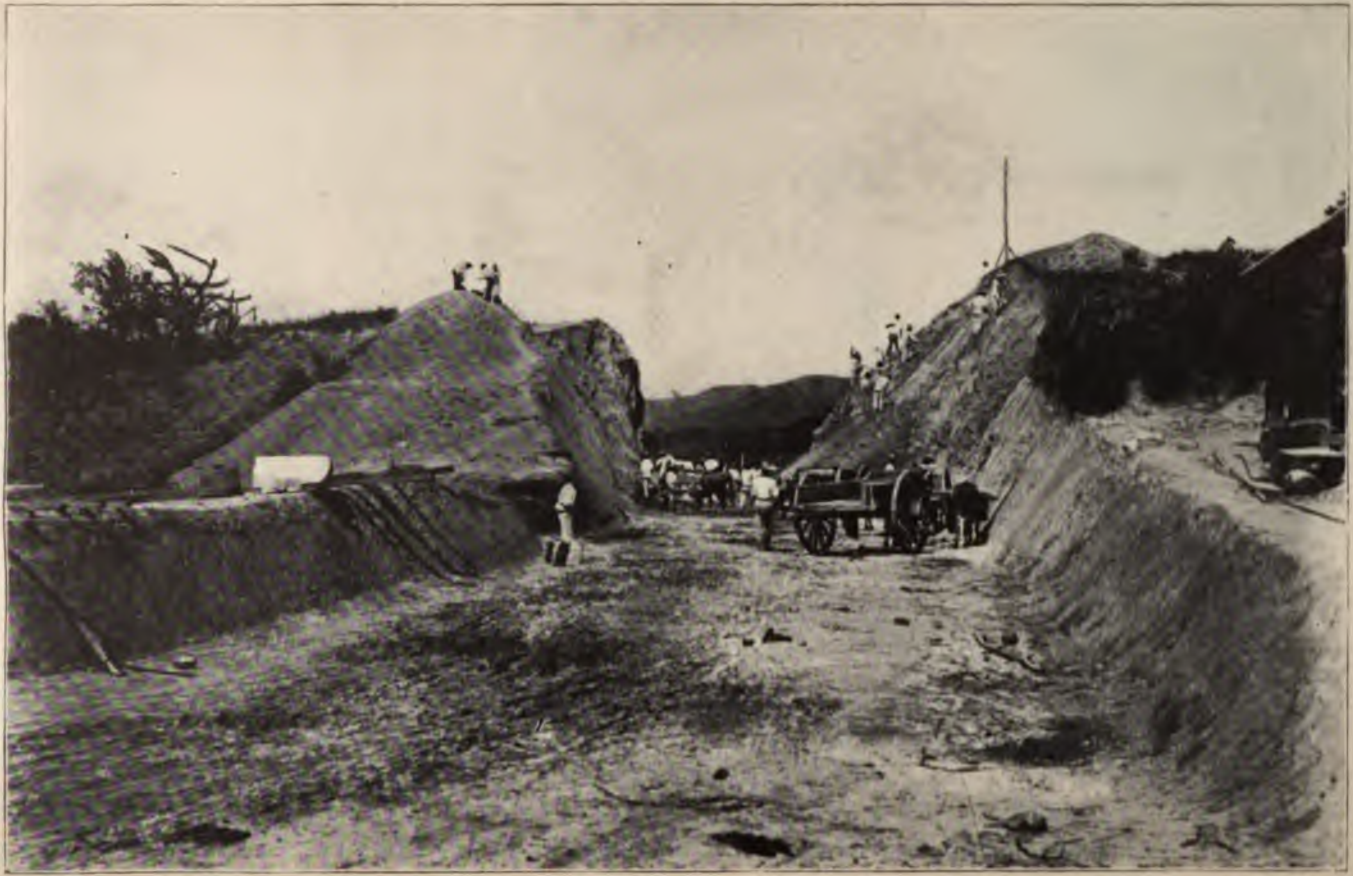


ROAD-BUILDING IN PORTO RICO

A heavy cut on road between Caguas and Humacao. Large hump on left bank of cut to be removed by blasting.

would these edges appear in their true lengths. It follows, then, that in isometrical drawing, true lengths appear only as 30° lines or as vertical lines. Edges or lines that in actual projection are either parallel to the ground line or perpendicular to V, are drawn in isometric as 30° lines, full length; and those that are actually vertical are made vertical in isometric, also full length.

In Fig. 45, lines such as the front vertical edges of the cube and the two base edges are called the three **isometric axes.** The isometric of objects in oblique positions, as in Fig. 48, can be constructed only by reference to their projections, by methods which will be explained later.

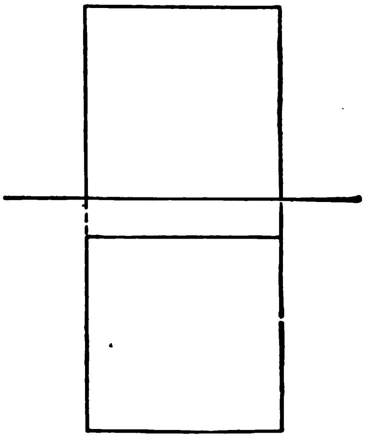


Fig. 47.

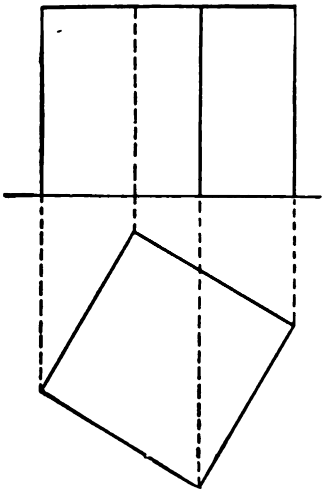


Fig. 48.

In isometric drawing small rectangular objects are more satisfactorily represented than large curved ones. In woodwork, mortises and joints and various parts of framing are well shown in isometric. This system is used also to give a kind of bird's-eye view of the mills or factories. It is also used in making sketches of small rectangular pieces of machinery, where it is desirable to give shape and dimensions in one view.

In isometric drawing the **direction of the ray of light** is parallel to that diagonal of a cube which runs from the upper left corner to the lower right corner, as 4^v-7^v in the last elevation of Fig. 45. This diagonal is at 30°; hence in isometrical drawing the direction of the light is at 30° downward to the right. From this it follows that the top and two left-hand faces of the cube are light, the others dark. This explains the shade lines in Fig. 45.

In Fig. 45, the top end of the diagonal which is parallel to the ray of light in the first position is marked 4, and traced through to the last or isometrical projection, 4^{v}. It will be seen that face $3^{v}\ 4^{v}\ 5^{v}\ 8^{v}$ of the isometric projection is the front face of the cube in the first view; hence we may consider the left front face of the isometric cube as the front. This is not absolutely necessary, but by so doing the isometric shade edges are exactly the same as on the original projection.

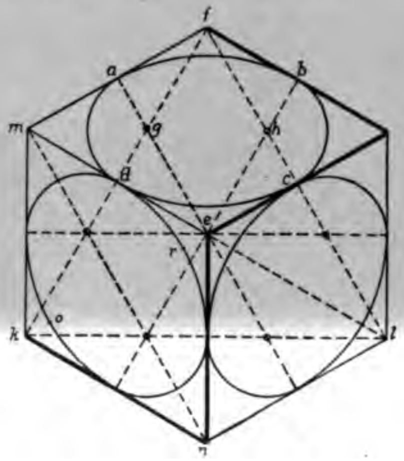


Fig. 49.

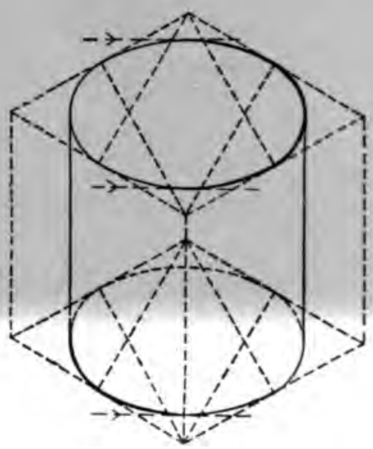


Fig. 50.

Fig. 49 shows a cube with circles inscribed in the top and two side faces. The isometric of a circle is an ellipse, the exact construction of which would necessitate finding a number of points; for this reason an approximate construction by arcs of circles is often made. In the method of Fig. 49, four centers are used. Considering the upper face of the cube, lines are drawn from the obtuse angles *f* and *e*, to the centers of the opposite sides.

The intersections of these lines give points *g* and *h*, which serve as centers for the ends of the ellipse. With center *g* and radius *g a*, the arc *a d* is drawn; and with *f* as center and radius *f d*, the arc *d c* is described, and the ellipse finished by using centers *h* and *e*. This construction is applied to all three faces.

Fig. 50 is the isometric of a cylinder standing on its base.

Notice that the shade line on the top begins and ends where T-square lines would be tangent to the curve, and similarly in the case of the part shown on the base. The explanation of the shade is very similar to that in projections. Given in projections a cylinder standing on its base, the plan is a circle, and the shade line is determined by applying the 45° triangle tangent to the circle. This is done because the 45° line is the projection of the ray of light on the plane of the base.

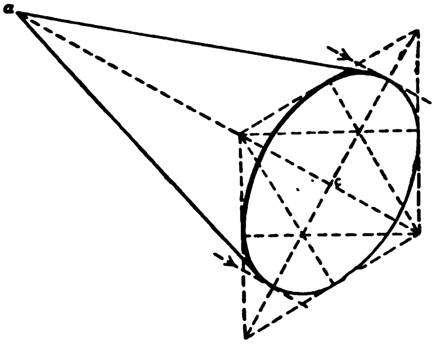


Fig. 51.

In Fig. 49, the diagonal *m l* may represent the ray of light and its projection on the base is seen to be *k l*, the diagonal of the base, a T-square line. Hence, for the cylinder of Fig. 50, apply tangent to the base and also to the top a line parallel to the projection of the ray of light on these planes, that is, a T-square line, and this will mark the beginning and ending of the shade line.

In Fig. 49 the projection of the ray of light diagonal *m l* on the right-hand face is *e l*, a 30° line; hence, in Fig. 51, where the base is similarly placed, apply the 30° triangle tangent as indicated, determining the shade line of the base. If the ellipse on the left-hand face of the cube were the base of a cone or cylinder extending backward to the right, the same principle would be used.

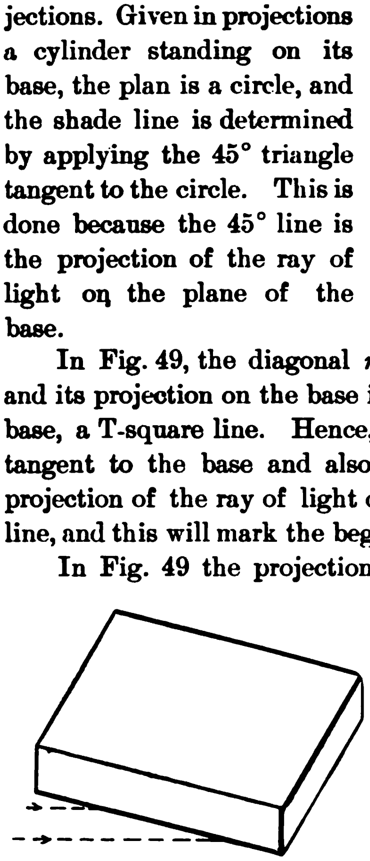


Fig. 52.

The projection of the cube diagonal *m l* on that face is *m n*, a 60° line; hence the 60° triangle would be used tangent to the base in this last supposed case, giving the ends of the shade line at points *o* and *r*. Figs. 52, 53 and 54 illustrate the same idea with respect to prisms, the direction of the projection of the ray of light on the plane of the base being used in each case to determine the light and dark faces and hence the shade lines.

In Fig. 52 a prism is represented standing on its base, so that the projection of the cube diagonal on the base (that is, a T-square line) is used to determine the light and dark faces as shown. The prism in Fig. 53 has for its base a trapezium. The projection of the ray of light on this end is parallel to the diagonal of the face; hence the 60° triangle applied parallel to this diagonal shows that faces *a c d b* and *a g h b* are light, while *c e f d* and *g e f h* are dark, hence the shade lines as shown.

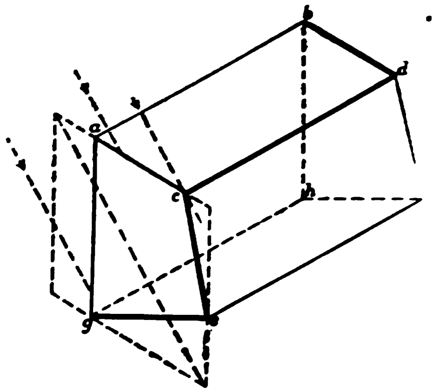


Fig. 53.

The application in Fig. 54 is the same, the only difference being in the position of the prism, and the consequent difference in the direction of the diagonal.

Fig. 55 represents a block with smaller blocks projecting from three faces.

Fig. 56 shows a framework of three pieces, two at right angles and a slanting brace. The horizontal piece is mortised into the upright, as indicated by the dotted lines. In Fig. 57 the isometric outline of a house is represented, showing a dormer window and a partial hip roof; *a b* is a hip rafter, *c d* a valley. Let the pitch of the main roof be shown at B, and let *m* be the middle point of the top of the end wall of the house. Then, by measuring vertically up a distance *m l* equal to the vertical height *a n* shown at B, a point on the line of the ridge will be found at *l*. Line *l i* is equal to *b h*, and *i h* is then drawn. Let the pitch of

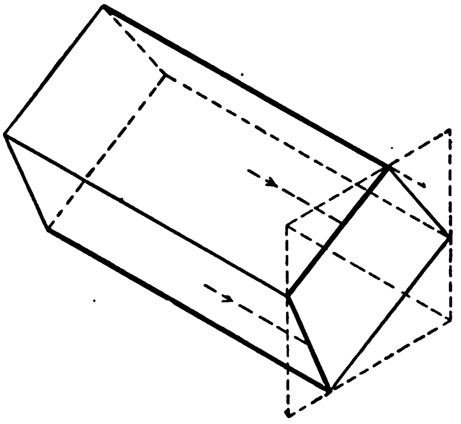


Fig. 54.

ıe end roof be given at A. This shows that the peak of the roof; r the end *a* of the ridge, will be back from the end wall a distance qual to the base of the triangle at A. Hence lay off from *l* this listance, giving point *a*, and join *a* with *b* and *x*.

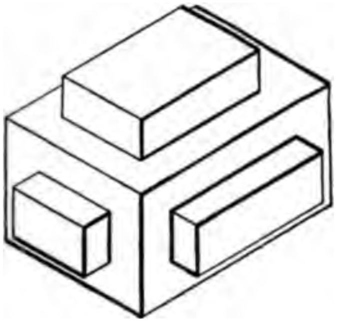


Fig. 55.

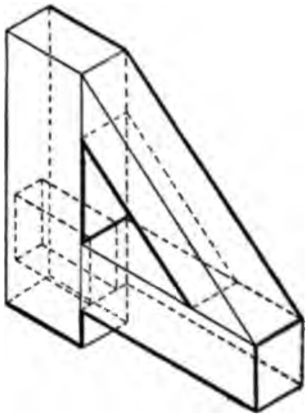


Fig. 56.

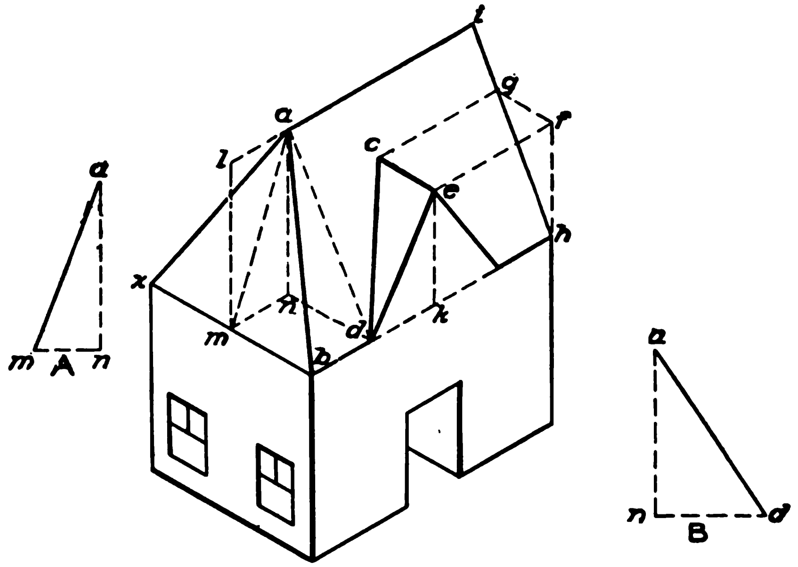


Fig. 57.

The height *k e* of the ridge of the dormer roof is known, and we must find where this ridge will meet the main roof. The ridge must be a 30° line as it runs parallel to the end wall of the house and to the ground. Draw from *e* a line parallel to *b h* to meet a vertical through *h* at *f*. This point is in the vertical plane of the end wall of the house, hence in the plane of *i h*. If now a 30° line be drawn from *f* parallel to *x b*, it will meet the roof of the house at *g*. The dormer ridge and *f g* are in the same horizontal plane, hence will meet the roof at the same distance below the ridge *a i*. Therefore draw the 30° line *g c*, and connect *c* with *d*.

In Fig. 58 a box is shown with the cover opened through 150°.

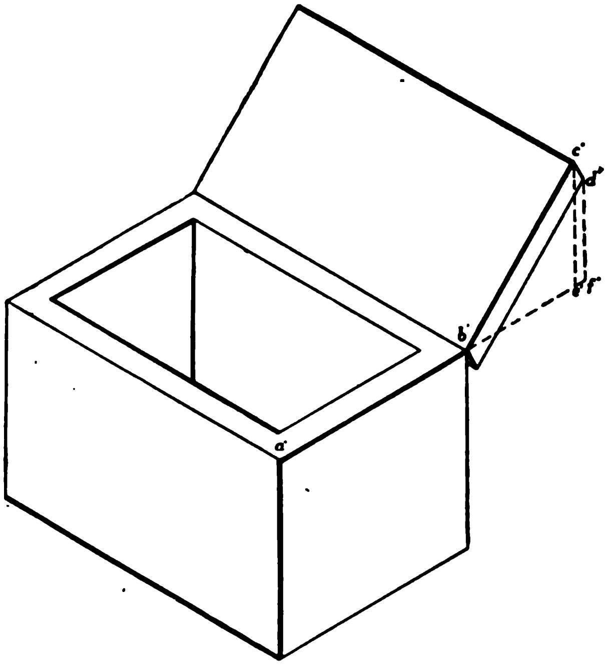


Fig. 58.

The right-hand edge of the bottom shows the width, the left-hand edge the length, and the vertical edge the height. The short edges of the cover are not isometric lines, hence are not shown in their true lengths; neither is the angle through which the cover is opened represented in its actual size.

The corners of the cover must then be determined by coordinates from an end view of the box and cover. As the end of the cover is in the same plane as the end of the box, the simple end view as shown in Fig. 59 will be sufficient. Extend the top of the box to the right, and from *c* and *d* let fall perpendiculars or *a b* produced, giving the points *e* and *f*. The point *c* may be located by means of the two distances or co-ordinates *b e* and *e c*.

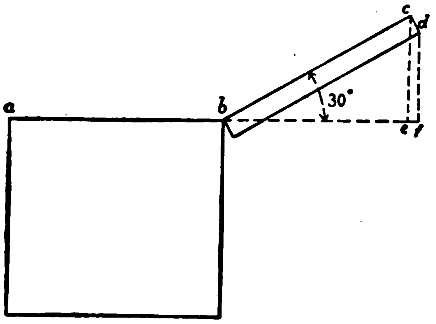


Fig. 59.

and these distances will appear in their true lengths in the isometric view. Hence produce *a' b'* to *e'* and *f'*; and from these points draw verticals *e' c'* and *f' d'*; make *b' e'* equal to *b e*, *e' c'* equal to *e c*; and similarly for *d'*. Draw the lower edge parallel to *c' d'* and equal to it in length, and connect with *b'*.

It will be seen that in isometric drawing parallel lines always appear parallel. It is also true that lines divided proportionally maintain this same relation in isometric drawing.

Fig. 60 shows a block or prism with a semicircular top. Find the isometric of the square circumscribing the circle, then draw the curve by the approximate method. The centers for the back face are found by projecting the front centers back 30° equal to the thickness of the prism, as shown at *a* and *b*. The plan and elevation of an oblique pentagonal pyramid are shown in Fig. 61. It is evident that none of the edges of the pyramid can be drawn in isometric as either vertical or 30° lines; hence, a system of co-ordinates must be used as

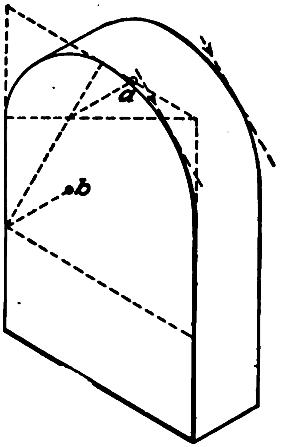


Fig. 60.

shown in Fig. 58. This problem illustrates the most general case; and to locate some of the points three co-ordinates must be used, two at 30° and one vertical.

Circumscribe, about the plan of the pyramid, a rectangle which shall have its sides respectively parallel and perpendicular to the ground line. This rectangle is on H, and its vertical projection is in the ground line.

The isometric of this rectangle can be drawn at once with 30° lines, as shown in Fig. 62, *o* being the same point in both figures.

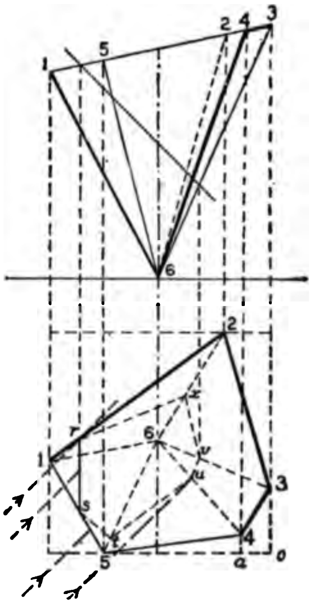


Fig. 61.

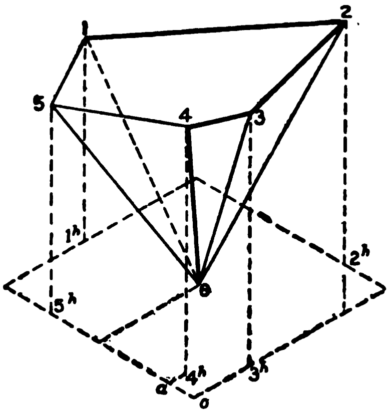


Fig. 62.

The horizontal projection of point 3 is found in isometric at 3^h, at the same distance from *o* as in the plan. That is, *any distance which in plan is parallel to a side of the circumscribing rectangle, is shown in isometric in its true length and parallel to the corresponding side of the isometric rectangle.* If point 3 were on the horizontal plane its isometric would be 3^h, but the point is at the vertical height above H given in the elevation; hence, lay off above 3^h this vertical height, obtaining the actual isometric of the point. To locate 4, draw 4 *a* parallel to the side of the rectangle; then lay off *o a* and *a* 4^h, giving what may be called the isometric plan of 4 Next, the vertical height taken from the elevation locates the isometric of the point in space.

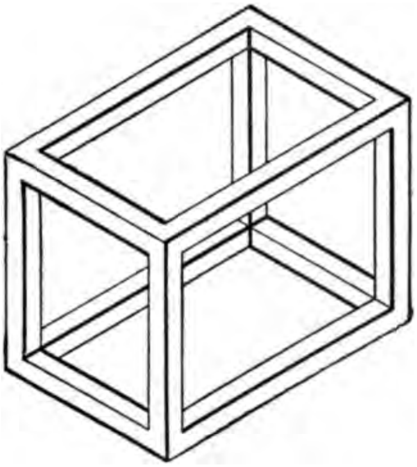


Fig. 63.

In like manner all the corners of the pyramid, including the apex, are located. The rule is, *locate first in isometric the horizontal projection of a point by one or two 30° co-ordinates; then vertically, above this point, its height as taken from the elevation.* The shade lines cannot be determined here by applying the 30° or 60° triangle, owing to the obliquity of the faces. Since the right front corner of the rectangle in plan was made the point *o* in isometric, the shade lines must be the same in isometric as in actual projection; so that, if these can be determined in Fig. 61, they may be applied at once to Fig. 62.

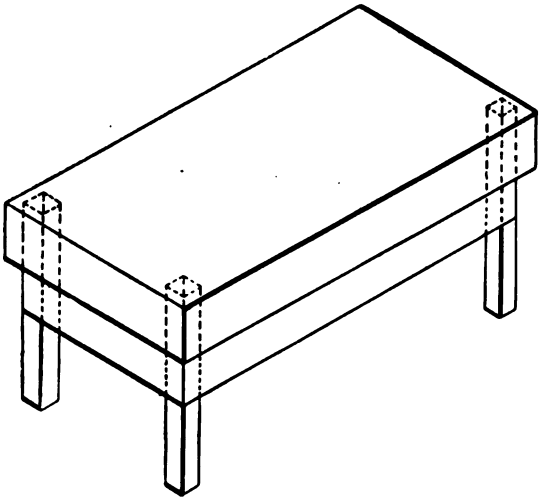


Fig. 64.

The shade lines in Fig. 61 are found by a short method which is convenient to use when the exact shade lines are desired, and when they cannot be determined by applying the 45° triangle. A plane is taken at 45° with the horizontal plane, and parallel to the direction of the ray of light, in such a position as to cut all the surfaces of the pyramid, as shown in elevation. This plane is perpendicular to the vertical plane; hence the section it cuts from the pyramid is readily found in plan by projection. This plane contains some of the rays of light falling upon the pyramid; and we can tell what surfaces these rays strike and make light, by noticing on the plan what edges of the section are struck by the projections of the rays of light. That is, *r s*, *s t*, and *t u* receive the rays of light; hence the surfaces on which these lines lie are light. *r s* is on the surface determined by the two lines passing

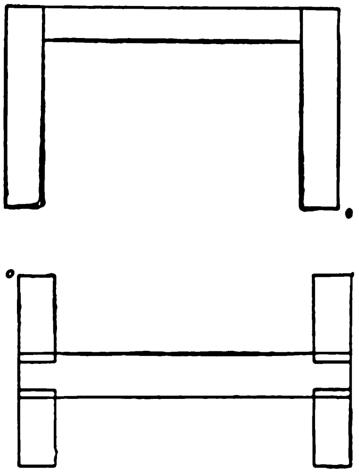


Fig. 65.

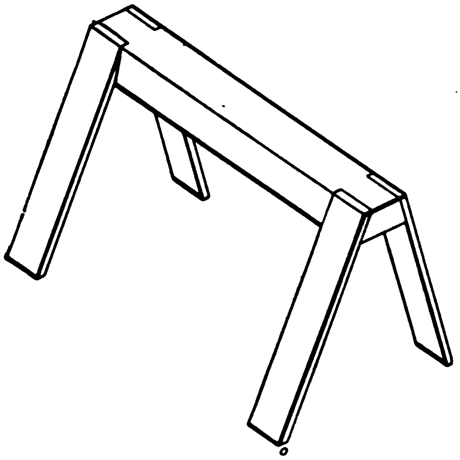


Fig. 66.

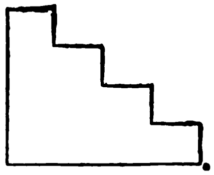


Fig. 67.

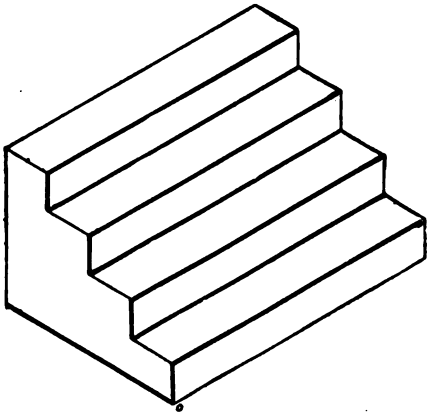


Fig. 68.

through *r* and *s*, namely, 2 — 1 and 1 — 5; in other words, *r s* is on the base; similarly, *s t* is on the surface 1 — 5 — 6; and *t u* on the surface 4 — 6 — 5. The other surfaces are dark; hence the edges which are between the light and dark faces are the shade lines.

Whenever it is more convenient, a plane parallel to the ray of light and perpendicular to H may be taken, the section found in elevation, and the 45° triangle applied to this section. The same method may be used to determine the exact shade lines of a cone or cylinder in an oblique position.

Figs. 63 to 70 give examples of the isometric of various objects. Fig. 65 is the plan and elevation, and Fig. 66 the isometric, of a carpenter's bench. In Fig. 70, take especial notice of the shade lines. These are put on as if the group were made in one piece; and the shadows cast by the blocks on one another are disregarded. All upper horizontal faces are light, all left-hand (front and back) faces light, and the rest dark.

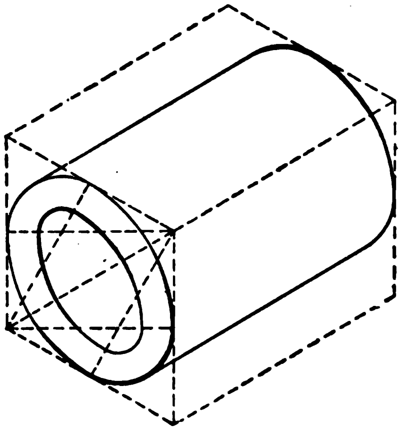


Fig. 69.

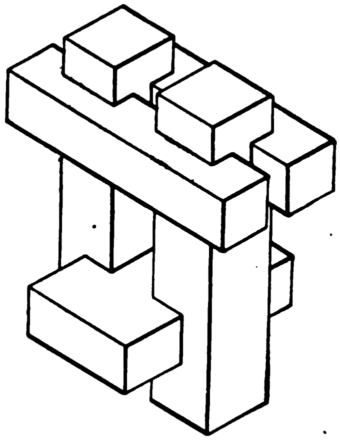


Fig. 70.

OBLIQUE PROJECTIONS.

In oblique projection, as in isometric, the end sought for is the same—a more or less complete representation, in one view, of any object. Oblique projection differs from isometric in that one face of the object is represented as if parallel to the vertical plane of projection, the others inclined to it. Another point of difference is that oblique projection cannot be derived from orthographic projection, as is isometric.

In oblique projection all lines in the front face are shown in their true lengths and in their true relation to one another, and lines which are perpendicular to this front face are shown in their true lengths at any angle that may be desired for any particular case. Lines not in the plane of the front face nor perpendicular to it must be determined by co-ordinates, as in isometric. It will be seen at once that this system possesses some advantages over the isometric, as, for instance, in the representation of circles, as any circle or curve in the front face is actually drawn as such.

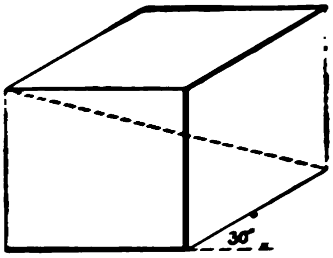


Fig. 71.

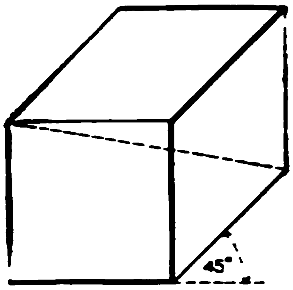


Fig. 72.

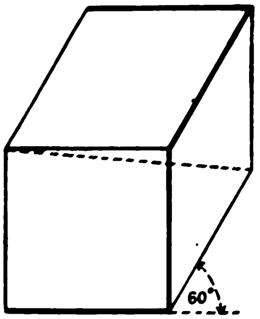


Fig. 73.

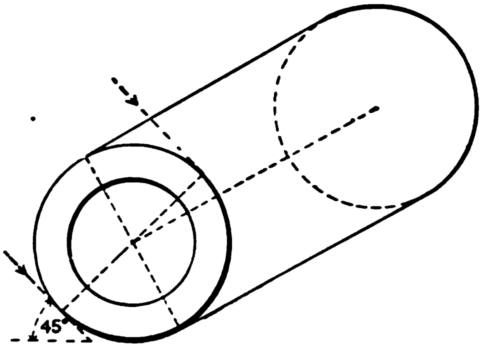


Fig. 74.

The rays of light are still supposed to be parallel to the same diagonal of the cube, that is, sloping downward, toward the plane of projection, and to the right, or downward, backward and to the right. Figs. 71, 72 and 73 show a cube in oblique projection, with the 30°, 45° and 60° slant respectively. The dotted diagonal represents for each case the direction of the light, and the shade lines follow from this.

The shade lines have the same general position as in isometric drawing, the top, front and left-hand faces being light. No matter what angle may be used for the edges that are perpendicular to the front face, the projection of the diagonal of the cube on this face is always a 45° line; hence, for determining the shade lines on any front face, such as the end of the hollow cylinder in Fig. 74, the 45° line is used exactly as in the elevation of ordinary projections.

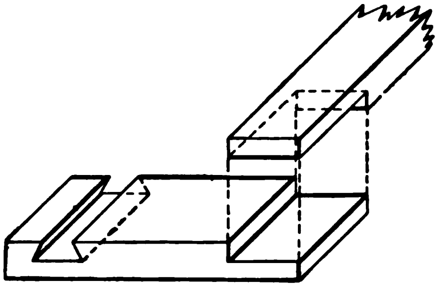


Fig. 75.

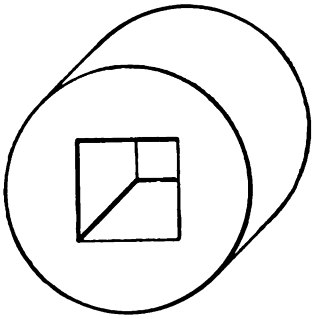


Fig. 76.

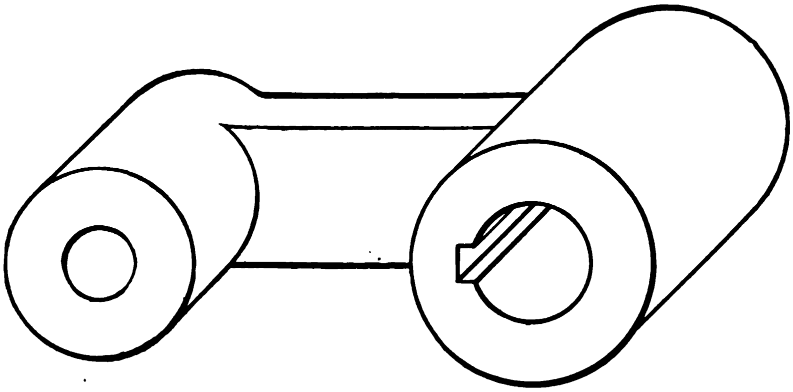


Fig. 77.

Figs. 75, 76, 77 and 79 are other examples of oblique projections. Fig. 77 is a crank arm.

The method of using co-ordinates for lines of which the true lengths are not shown, is illustrated by Figs. 78 and 79. Fig. 79 represents the oblique projection of the two joists shown in plan and elevation in Fig. 78. The dotted lines in the elevation (see Fig. 78) show the heights of the corners above the horizontal stick. The feet of these perpendiculars give the horizontal distances of the top corners from the end of the horizontal piece.

In Fig. 79 lay off from the upper right-hand corner of the front end a distance equal to the distance between the front edge of the inclined piece and the front edge of the bottom piece (see Fig. 78). From this point draw a dotted line parallel to the length. The horizontal distances from the upper left corner to the dotted perpendicular are then marked off on this line. From these points verticals are drawn, and made equal in length to the dotted perpendiculars of Fig. 78, thus locating two corners of the end.

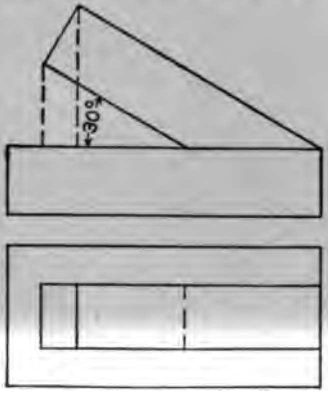


Fig. 78.

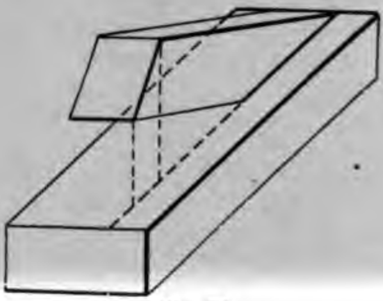


Fig. 79

LINE SHADING.

In finely finished drawings it is frequently desirable to make the various parts more readily seen by showing the graduations of light and shade on the curved surfaces. This is especially true of such surfaces as cylinders, cones and spheres. The effect is obtained by drawing a series of parallel or converging lines on the surface at varying distances from one another. Sometimes draftsmen vary the width of the lines themselves. These lines are farther apart on the lighter portion of the surface, and are closer together and heavier on the darker part.

Fig. 80 shows a cylinder with elements drawn on the surface equally spaced, as on the plan. On account of the curvature of the surface the elements are not equally spaced on the elevation, but give the effect of graduation of light. The result is that in elevation the distances between the elements gradually lessen from the center toward each side, thus showing that the cylinder is convex. The effect is intensified, however, if the elements are made heavier, as well as closer together, as shown in Figs. 81 to 87.

Cylinders are often shaded with the light coming in the usual way, the darkest part commencing about where the shade line would actually be on the surface, and the lightest portion a little to the left of the center. Fig. 81 is a cylinder showing the heaviest shade at the right, as this method is often used. Considerable practice is necessary in order to obtain good results; but in this, as in other portions of mechanical drawing, perseverance has its reward. Fig. 82 represents a cylinder in a horizontal position, and Fig. 83 represents a section of a hollow vertical cylinder.

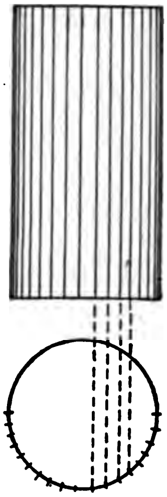


Fig. 80.

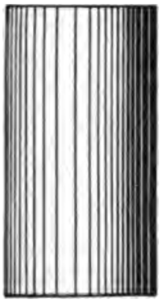


Fig. 81.

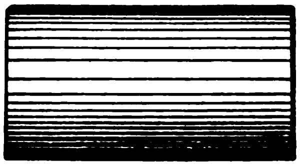


Fig. 82.

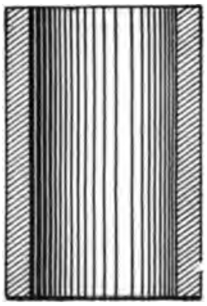


Fig. 83.

Figs. 84 to 87 give other examples of familiar objects.

In the elevation of the cone shown in Fig. 87 the shade lines should diminish in weight as they approach the apex. Unless this is done it will be difficult to avoid the formation of a blot at that point.

LETTERING.

All working drawings require more or less lettering, such as titles, dimensions, explanations, etc. In order that the drawing may appear finished, the lettering must be well done. No style of lettering should ever be used which is not perfectly legible. It is generally best to use plain, easily-made letters which present a neat appearance. Small letters used on the drawing for notes or directions should be made free-hand with an ordinary writing pen. Two horizontal guide lines should be used to limit the height of the letters; after a time, however, the upper guide line may be omitted.

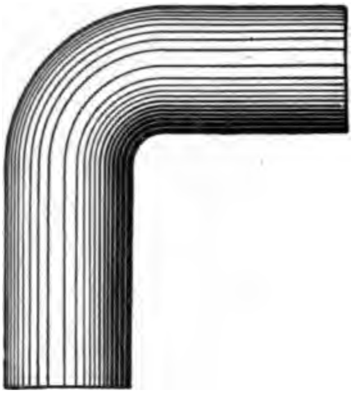


Fig. 84.

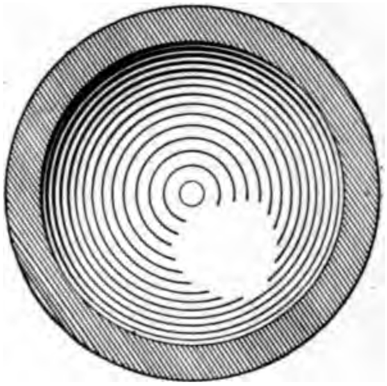


Fig. 85.

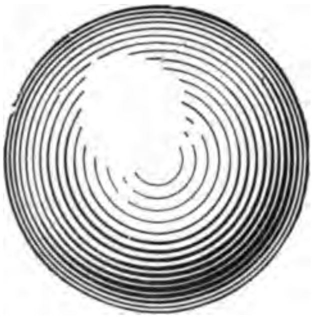


Fig. 86.

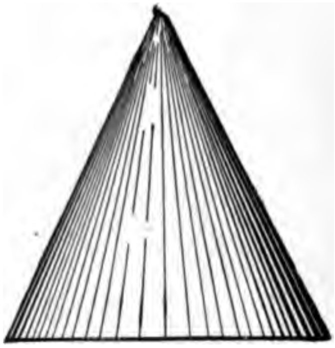
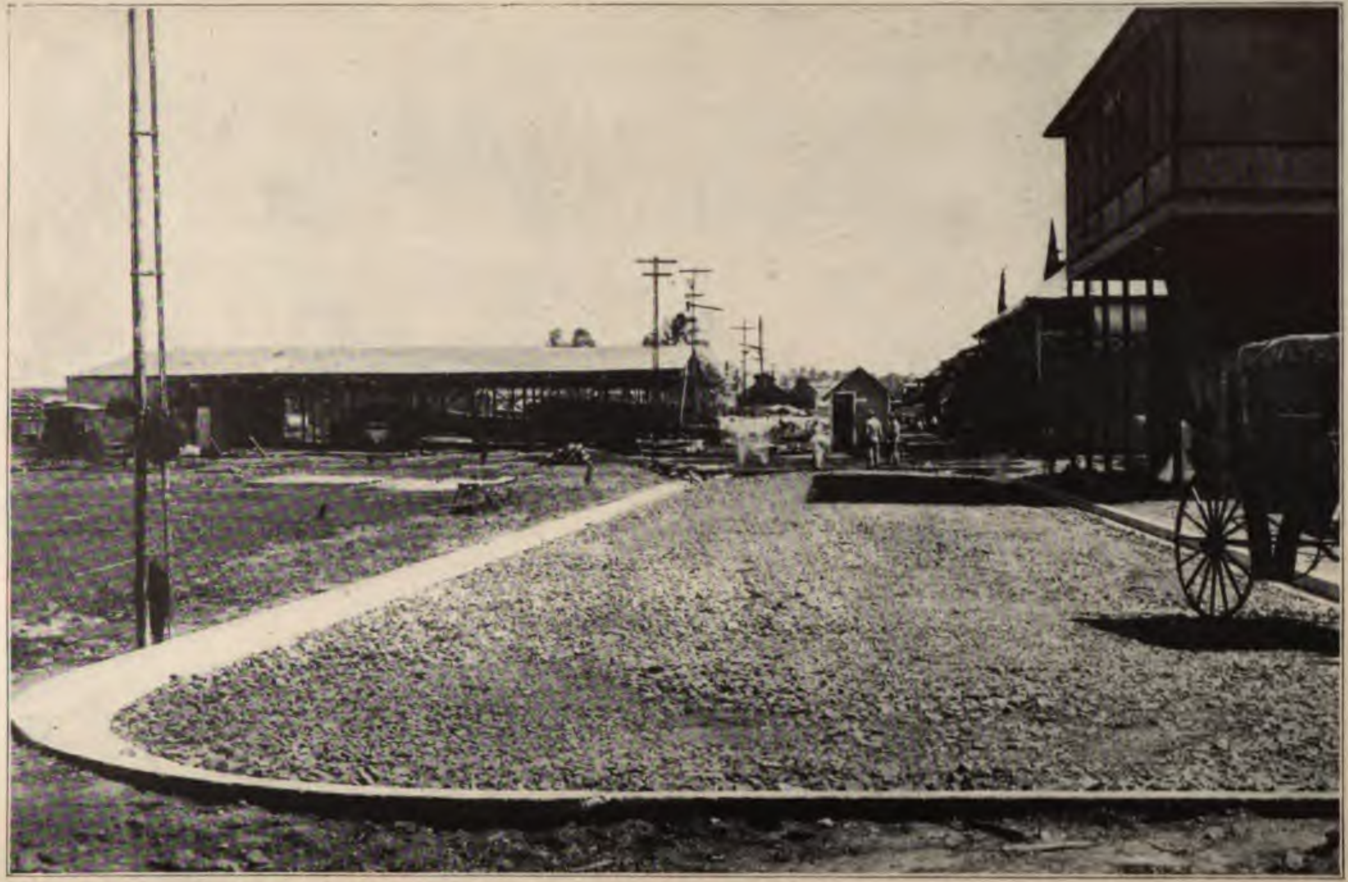


Fig. 87.

[illegible] RARY
TI [illegible] NOX
[illegible]



IMPROVEMENT OF THE CITY OF COLON, PANAMA

Second Street, looking toward D Street, after paving. For view of same street before paving, see page 362.

In the early part of this course the inclined Gothic letter was described, and the alphabet given. The Roman, Gothic and block letters are perhaps the most used for titles. These letters, being of comparatively large size, are generally made mechanically; that is, drawing instruments are used in their construction. In order that the letters may appear of the same height, some of them, owing to their shape, must be made a little higher than the others. This is the case with the letters curved at the top and bottom, such as C, O, S, etc., as shown somewhat exaggerated in Fig. 88. Also, the letter A should extend a little above, and V a little below, the guide lines, because if made of the same height as the others they will appear shorter. This is true of all capitals, whether of Roman, Gothic, or other alphabets. In the block letter, however, they are frequently all of the same size.

There is no absolute size or proportion of letters, as the dimensions are regulated by the amount of space in which the letters are to be placed, the size of the drawing, the effect desired, etc. In some cases letters are made so that the height is greater than the width, and sometimes the reverse; sometimes the height and width are the same. This last proportion is the most common. Certain relations of width, however, should be observed. Thus, in whatever style of alphabet used, the W should be the widest letter; J the narrowest, M and T next widest to W, then A and B. The other letters are of about the same width.

In the vertical Gothic alphabet, the average height is that of B, D, E, F, etc., and the additional height of the curved letters and of the A and V is very slight. The horizontal cross lines of such letters as E, F, H, etc., are slightly above the center; those of A, G and P slightly below.

For the inclined letters, 60° is a convenient angle, although they may be at any other angle suited to the convenience or fancy of the draftsman. Many draftsmen use an angle of about 70°.

The letters of the Roman alphabet, whether vertical or inclined, are quite ornamental in effect if well made, the inclined Roman being a particularly attractive letter, although rather difficult to make. The block letter is made on the same general plan as the Gothic, but much heavier. Small squares are taken as

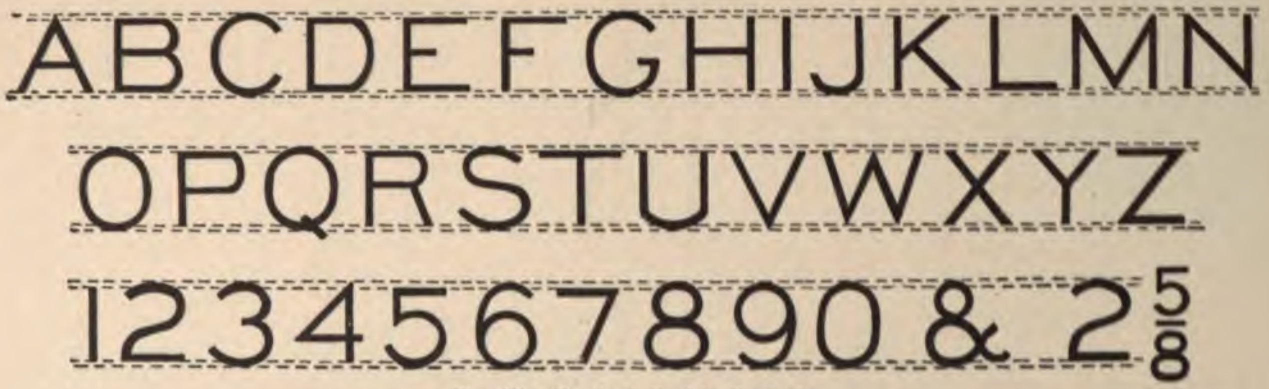
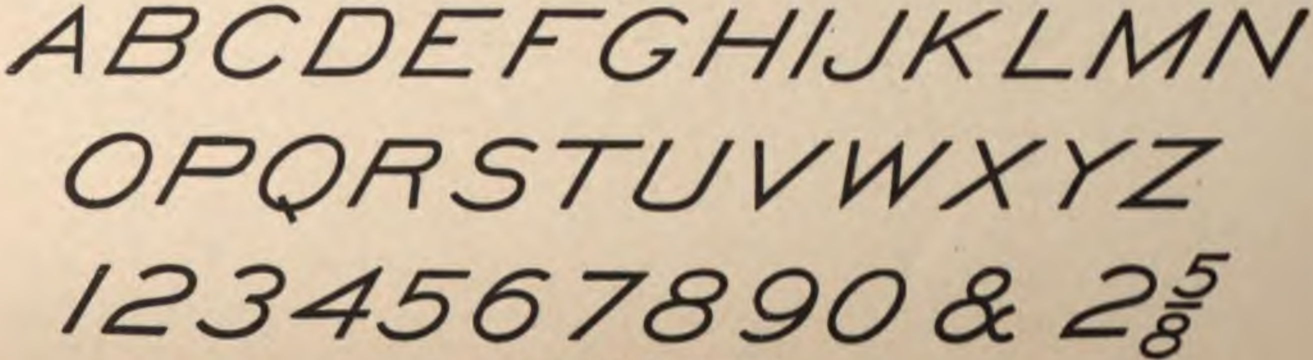


Fig. 88. Vertical Gothic Capitals.



Inclined Gothic Capitals.

the unit of measurement, as shown. The use of this letter is not advocated for general work, although if made merely in outline the effect is pleasing. The styles of numbers corresponding with the alphabets of capitals given here, are also inserted. When a fraction, such as $2\frac{5}{8}$ is to be made, the proportion should be about as shown. For small letters, usually called lower-case letters, the height may be made about two-thirds that of the capitals. This proportion, however, varies in special cases.

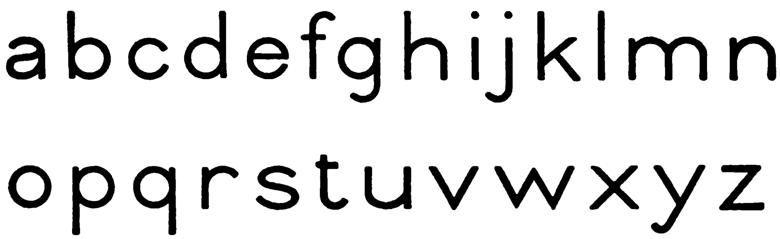


Fig. 89.

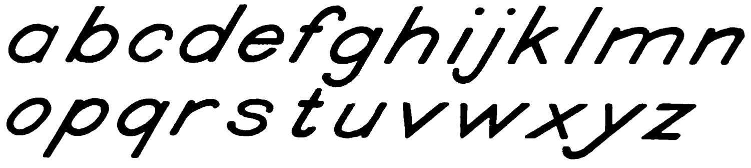


Fig. 90.

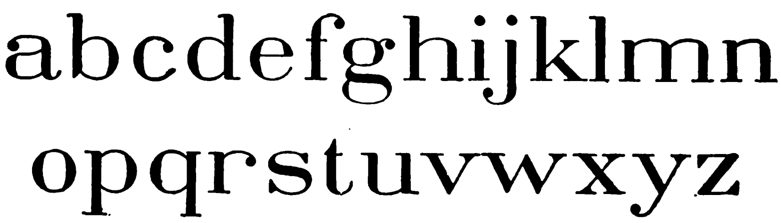


Fig. 91.

The principal lower-case letters in general use among draftsmen are shown in Figs. 89, 90, 91 and 92. The Gothic letters shown in Figs. 89 and 90 are much easier to make than the Roman letters in Figs. 91 and 92. These letters, however, do not

ABCDEFGHIJKLMN

OPQRSTUVWXYZ

1234567890 & $2\frac{5}{8}$

Vertical Roman Capitals.

ABCDEFGHIJKLMN

OPQRSTUVWXYZ

1234567890 & $2\frac{5}{8}$

Inclined Roman Capitals.

give as finished an appearance as the Roman. As has already been stated in Mechanical Drawing, Part I, the inclined letter is easier to make because slight errors are not so apparent.

One of the most important points to be remembered in lettering is the spacing. If the letters are finely executed but poorly spaced, the effect is not good. To space letters correctly and rapidly, requires considerable experience; and rules are of little value on account of the many combinations in which letters are found. A few directions, however, may be found helpful. For instance, take the word TECHNICALITY, Fig. 93. If all the spaces were made equal, the space between the L and the I would appear to be too great, and the same would apply to the space between the I and the T. The space between the H and the N and that between the N and the I would be insufficient. In general, when the vertical side of one letter is followed by the vertical side of another, as in H E, H B, I R, etc., the maximum space should be allowed. Where T and A come together the least space is given, for in this case the top of the T frequently extends over the bottom of the A. In general, the spacing should be such that a uniform appearance is obtained. For the distances between words in a sentence, a space of about 1½ the width of the average letter may be used. The space, however, depends largely upon the desired effect.

abcdefghijklmn

opqrstuvwxyz

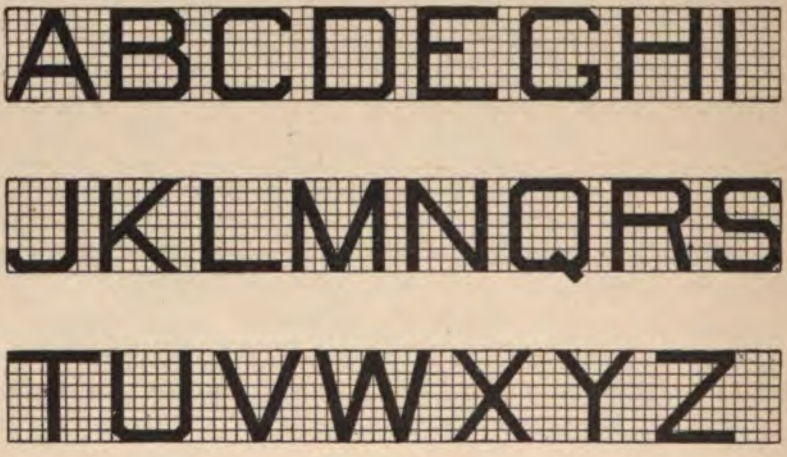
Fig. 92.

TECHNICALITY

Fig. 93.

For large titles, such as those placed on charts, maps, and some large working drawings, the letters should be penciled before inking. If the height is made equal to the width considerable time and labor will be saved in laying out the work. This is especially true with such Gothic letters as O, Q, C, etc., as these letters may then be made with compasses. If the letters are of sufficient size, the outlines may be drawn with the ruling pen or compasses, and the spaces between filled in with a fine brush.

The titles for working drawings are generally placed in the lower right-hand corner. Usually a draftsman has his choice of letters, mainly because after he has become used to making one style he can do it rapidly and accurately. However, in some drafting rooms the head draftsman decides what lettering shall be used. In making these titles, the different alphabets are selected to give the best results without spending too much time. In most work the letters are made in straight lines, although we frequently find a portion of the title lettered on an arc of a circle.



Block Letters.

In Fig. 94 is shown a title having the words CONNECTING ROD lettered on an arc of a circle. To do this work requires considerable patience and practice. First draw the vertical center line as shown at C in Fig. 94. Then draw horizontal lines for the horizontal letters. The radii of the arcs depend upon the general arrangement of the entire title, and this is a matter of taste. The difference between the arcs should equal the height of the letters. After the arc is drawn, the letters should be sketched in pencil to find their approximate positions. After this is done, draw radial lines from the center of the letters to the center of the arcs.

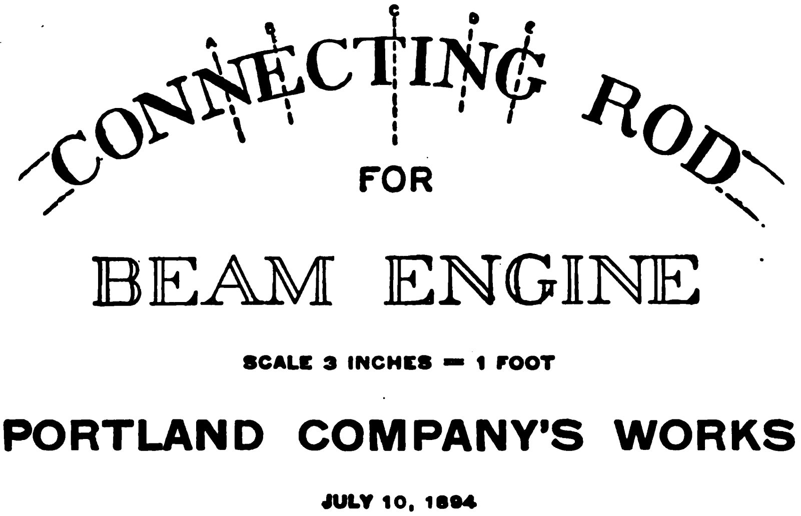


Fig. 94.

These lines will be the centers of the letters, as shown at A, B, D and E. The vertical lines of the letters should not radiate from the center of the arc, but should be parallel to the center lines already drawn; otherwise the letters will appear distorted. Thus, in the letter N the two verticals are parallel to the line A. The same applies to the other letters in the alphabet.

Tracing. Having finished the pencil drawing, the next step is the inking. In some offices the pencil drawing is made on a thin, tough paper, called board paper, and the inking is done over the pencil drawing, in the manner with which the student is already familiar. It is more common to do the inking on thin, transparent cloth, called tracing cloth, which is prepared for the purpose. This tracing cloth is made of various kinds, the kind in ordinary use being what is known as "dull back," that is, one side is finished and the other side is left dull. Either side may be used to draw upon, but most draftsmen prefer the dull side. If a drawing is to be traced it is a good plan to use a 3H or 4H pencil, so that the lines may be easily seen through the cloth.

The tracing cloth is stretched smoothly over the pencil drawing and a little powdered chalk rubbed over it with a dry cloth, to remove the slight amount of grease or oil from the surface and make it take the ink better. The dust must be carefully brushed or wiped off with a soft cloth, after the rubbing, or it will interfere with the inking.

The drawing is then made in ink on the tracing cloth, after the same general rules as for inking the paper, but care must be taken to draw the ink lines exactly over the pencil lines which are on the paper underneath, and which should be just heavy enough to be easily seen through the tracing cloth. The ink lines should be firm and fully as heavy as for ordinary work. In tracing, it is better to complete one view at a time, because if parts of several views are traced and the drawing left for a day or two, the cloth is liable to stretch and warp so that it will be difficult to complete the views and make the new lines fit those already drawn and at the same time conform to the pencil lines underneath. For this reason it is well, when possible, to complete a view before leaving the drawing for any length of time, although of course on views in which there is a good deal of work this cannot always be done. In this case the draftsman must manipulate his tracing cloth and instruments to make the lines fit as best he can. A skillful draftsman will have no trouble from this source, but the beginner may at first find difficulty.

Inking on tracing cloth will be found by the beginner to be quite different from inking on the paper to which he has been accustomed, and he will doubtless make many blots and think at first that it is hard to make a tracing. After a little practice, however, he will find that the tracing cloth is very satisfactory and that a good drawing can be made on it quite as easily as on paper.

The necessity for making erasures should be avoided, as far as possible, but when an erasure must be made a good ink rubber or typewriter eraser may be used. If the erased line is to have ink placed on it, such as a line crossing, it is better to use a soft rubber eraser. All moisture should be kept from the cloth.

Blue Printing. The tracing, of course, cannot be sent into the shop for the workmen to use, as it would soon become soiled and in time destroyed, so that it is necessary to have some cheap and rapid means of making copies from it. These copies are made by the process of blue printing in which the tracing is used in a manner similar to the use made of a negative in photography.

Almost all drafting rooms have a frame for the purpose of making blue prints. These frames are made in many styles, some simple, some elaborate. A simple and efficient form is a flat surface usually of wood, covered with padding of soft material, such as felting. To this is hinged the cover, which consists of a frame similar to a picture frame, in which is set a piece of clear glass. The whole is either mounted on a track or on some sort of a swinging arm, so that it may readily be run in and out of a window.

The print is made on paper prepared for the purpose by having one of its surfaces coated with chemicals which are sensitive to sunlight. This coated paper, or blue-print paper, as it is called, is laid on the padded surface of the frame with its coated side uppermost; the tracing laid over it right side up, and the glass pressed down firmly and fastened in place. Springs are frequently used to keep the paper, tracing, etc., against the glass. With some frames it is more convenient to turn them over and remove the backs. In such cases the tracing is laid against the glass, face down; the coated paper is then placed on it with the coated side against the tracing cloth.

The sun is allowed to shine upon the drawing for a few minutes, then the blue-print paper is taken out and thoroughly washed in clean water for several minutes and hung up to dry.

If the paper has been recently prepared and the exposure properly timed, the coated surface of the paper will now be of a clear, deep blue color, except where it was covered by the ink lines, where it will be perfectly white.

The action has been this: Before the paper was exposed to the light the coating was of a pale yellow color, and if it had then been put in water the coating would have all washed off, leaving the paper white. In other words, before being exposed to the sunlight the coating was soluble. The light penetrated the transparent tracing cloth and acted upon the chemicals of the coating, changing their nature so that they became insoluble; that is, when put in water, the coating, instead of being washed off, merely turned blue. The light could not penetrate the ink with which the lines, figures, etc., were drawn, consequently the coating under these was not acted upon and it washed off when put in water, leaving a white copy of the ink drawing on a blue background. If running water cannot be used, the paper must be washed in a sufficient number of changes until the water is clear. It is a good plan to arrange a tank having an overflow, so that the water may remain at a depth of about 6 or 8 inches.

The length of time to which a print should be exposed to the light depends upon the quality and freshness of the paper, the chemicals used and the brightness of the light. Some paper is prepared so that an exposure of one minute, or even less, in bright sunlight, will give a good print and the time ranges from this to twenty minutes or more, according to the proportions of the various chemicals in the coating. If the full strength of the sunlight does not strike the paper, as, for instance, if clouds partly cover the sun, the time of exposure must be lengthened.

Assembly Drawing. We have followed through the process of making a detail drawing from the sketches to the blue print ready for the workmen. Such a detail drawing or set of drawings shows the form and size of each piece, but does not show how the pieces go together and gives no idea of the machine as a whole. Consequently, a general drawing or assembly drawing must be made, which will show these things. Usually two or more views are necessary, the number depending upon the complexity of the machine. Very often a cross-section through some part of the machine, chosen so as to give the best general idea with the least amount of work, will make the drawing clearer.

The number of dimensions required on an assembly drawing depends largely upon the kind of machine. It is usually best to give the important over-all dimensions and the distance between the principal center lines. Care must be taken that the over-all dimensions agree with the sum of the dimensions of the various details. For example, suppose three pieces are bolted together, the thickness of the pieces according to the detail drawing, being one inch, two inches, and five and one-half inches respectively; the sum of these three dimensions' is eight and one-half inches and the dimensions from outside on the assembly drawing, if given at all, must agree with this. It is a good plan to add these over-all dimensions, as it serves as a check and relieves the mechanic of the necessity of adding fractions.

FORMULA FOR BLUE-PRINT SOLUTION.

Dissolve thoroughly and filter.

A.	Red Prussiate of potash	2½ ounces,
	Water	1 pint.
B.	Ammonio-Citrate of iron	4 ounces,
	Water	1 pint

Use equal parts of A and B.

FORMULA FOR BLACK PRINTS

Negatives. White lines on blue ground; prepare the paper with

Ammonio-Citrate of iron	40 grains,
Water	1 ounce.

After printing wash in water.

Positives. Black lines on white ground; prepare the paper with:

Iron perchloride	616 grains,
Oxalic Acid	308 grains,
Water	14 ounces.

Develop in	Gallic Acid	1 ounce,
	Citric Acid	1 ounce,
	Alum	8 ounces.

Use 1¼ ounces of developer to one gallon of water. **Paper** is **fully exposed when it has changed from yellow to white.**

PLATES.

PLATE IX.

The plates of this Instruction Paper should be laid out at the same size as the plates in Parts I and II. The center lines and border lines should also be drawn as described.

First draw two ground lines across the sheet, 3 inches below the upper border line and 3 inches above the lower border line. The first problem on each ground line is to be placed 1 inch from the left border line; and spaces of about 1 inch should be left between the figures.

Isolated points are indicated by a small cross X, and projections of lines are to be drawn full unless invisible. All construction lines should be fine dotted lines. Given and required lines should be drawn full.

Problems on Upper Ground Line:

1. Locate both projections of a point on the horizontal plane 1 inch from the vertical plane.

2. Draw the projections of a line 2 inches long which is parallel to the vertical plane and which makes an angle of 45 degrees with the horizontal plane and slants upward to the right. The line should be 1 inch from the vertical plane and the lower end ½ inch above the horizontal.

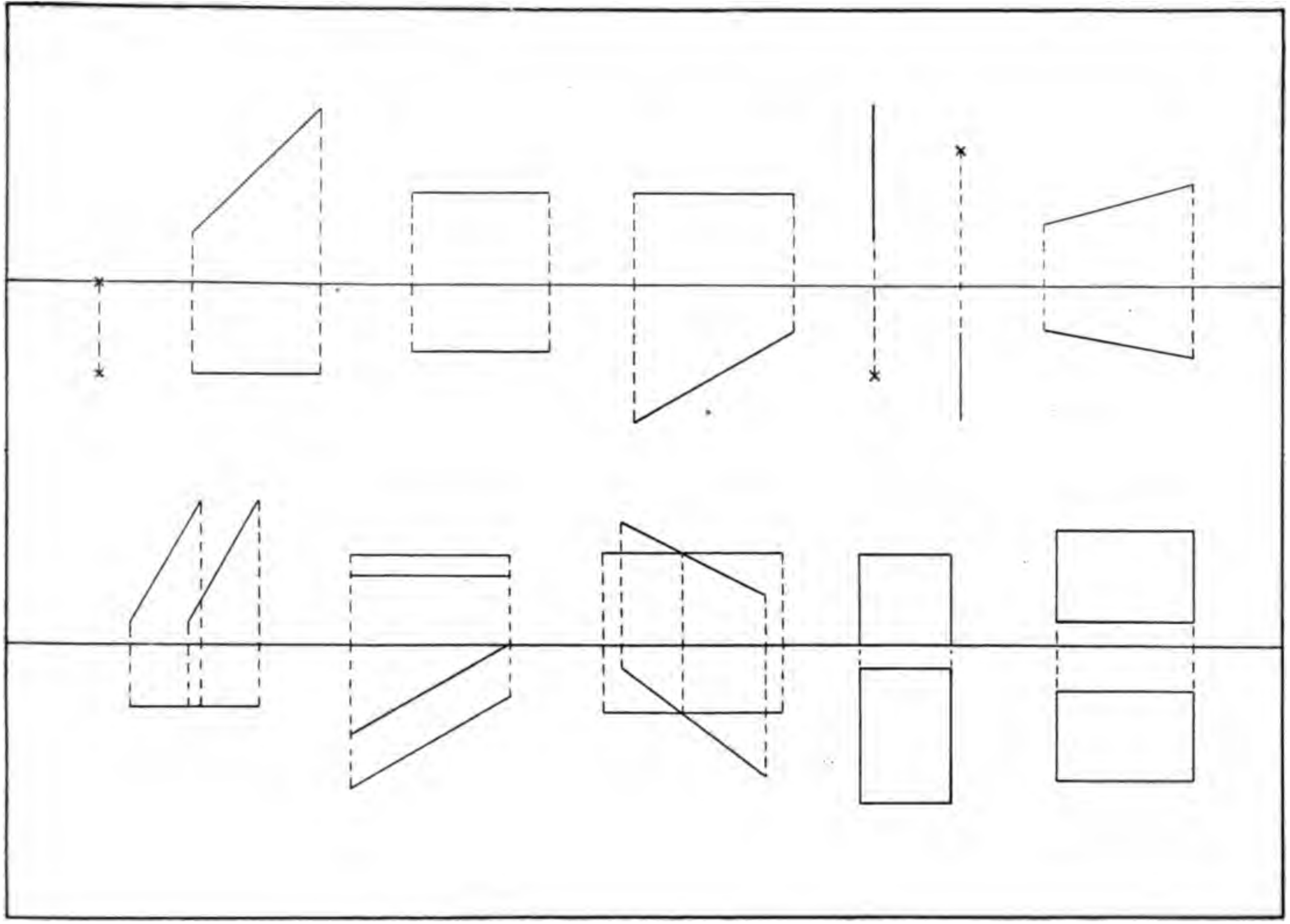
3 Draw the projections of a line 1½ inches long which is parallel to both planes. 1 inch above the horizontal, and ¾ inch from the vertical.

4. Draw the plan and elevation of a line 2 inches long which is parallel to H and makes an angle of 30 degrees with V. Let the right-hand end of the line be the end nearer V, ½ inch from V. The line to be 1 inch above H.

5. Draw the plan and elevation of a line 1½ inches long which is perpendicular to the horizontal plane and 1 inch from the vertical. Lower end of line is ½ inch above H.

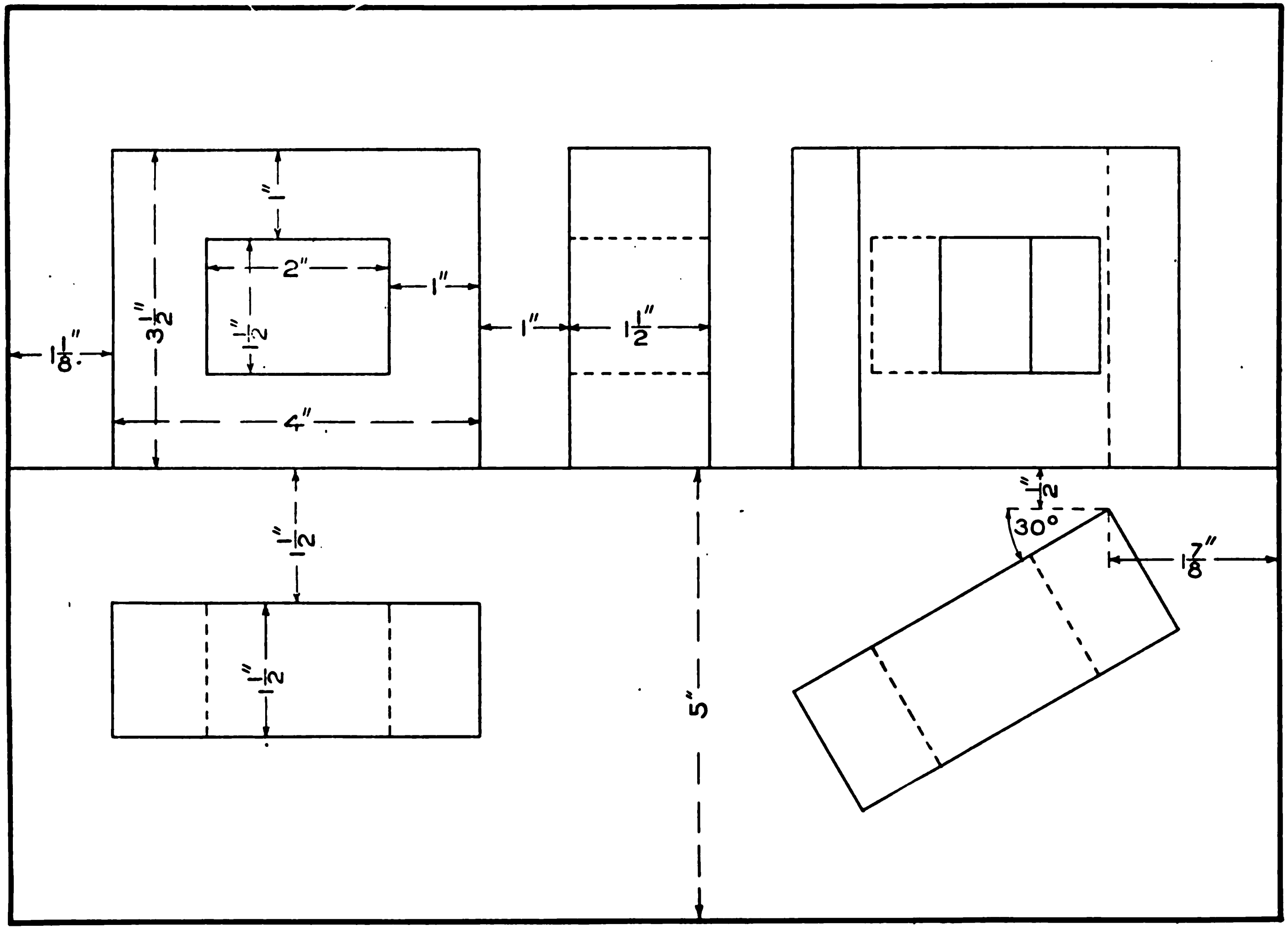
6. Draw the projections of a line 1 inch long which is perpendicular to the vertical plane and 1½ inches above the horizontal. The end of the line nearer V, or the back end, is ½ inch from V.

PLATE IX

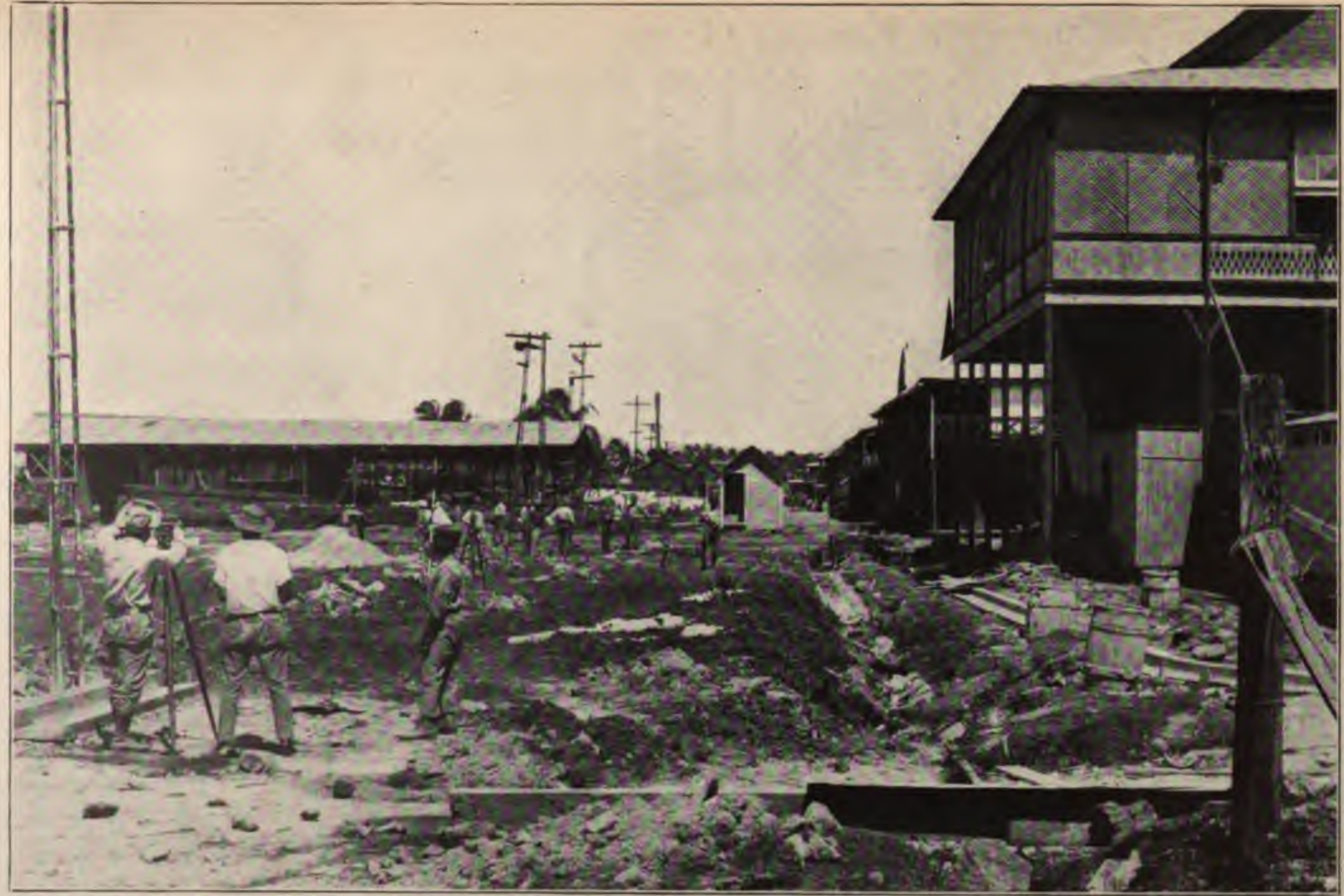


FEBRUARY 17, 1907 HERBERT CHANDLER, CHICAGO, ILL.

PLATE X



FEBRUARY 20, 1907 HERBERT CHANDLER CHICAGO, ILL.



IMPROVEMENT OF THE CITY OF COLON, PANAMA

Second Street, filled with disease-breeding filth, before paving. Surveyors taking levels for pavement. For view of same street after paving, see page 347

7. Draw two projections which shall represent a line oblique to both planes.

NOTE. Leave 1 inch between this figure and the right-hand border line.

Problems on Lower Ground Line:

8. Draw the projections of two parallel lines each 1½ inches long. The lines are to be parallel to the vertical plane and to make angles of 60 degrees with the horizontal. The lower end of each line is ¼ inch above H. The right-hand end of the right-hand line is to be 2¾ inches from the left-hand margin.

9. Draw the projections of two parallel lines each 2 inches long. Both lines to be parallel to the horizontal and to make an angle of 30 degrees with the vertical. The lower line to be ¾ inch above H, and one end of one line to be against V.

10. Draw the projections of two intersecting lines. One 2 inches long to be parallel to both planes, 1 inch above H, and ¾ inch from the vertical; and the other to be oblique to both planes and of any desired length.

11. Draw plan and elevation of a prism 1 inch square and 1½ inches long. The prism to have one side on the horizontal plane, and its long edges to be perpendicular to V. The back end of the prism is ¼ inch from the vertical plane.

12. Draw plan and elevation of a prism the same size as given above, but with the long edges parallel to both planes, the lower face of the prism to be parallel to H and ¼ inch above it. The back face to be ½ inch from V.

PLATE X.

The ground line is to be in the middle of the sheet, and the location and dimensions of the figures are to be as given. The first figure shows a rectangular block with a rectangular hole cut through from front to back. The other two figures represent the same block in different positions. The second figure is the end or profile projection of the block. The same face is on H in all three positions. Be careful not to omit the shade lines. The figures given on the plate for dimensions, etc., are to be used but not repeated on the plate by the student.

PLATE XI.

Three ground lines are to be used on this plate, two at the left 4½ inches long and 3 inches from top and bottom margin lines; and one at the right, half way between the top and bottom margins, 9½ inches long.

The figures 1, 2, 3 and 4 are examples for finding the true lengths of the lines. Begin No. 1 ¾ inch from the border, the vertical projection 1¾ inches long, one end on the ground line and inclined at 30°. The horizontal projection has one end ½ inch from V, and the other 1½ inches from V. Find the true length of the line by completing the construction commenced by swinging the arc, as shown in the figure.

Locate the left-hand end of No. 2 3 inches from the border, 1 inch above H, and ⅝ inch from V. Extend the vertical projection to the ground line at an angle of 45°, and make the horizontal projection at 30°. Complete the construction for true length as commenced in the figure.

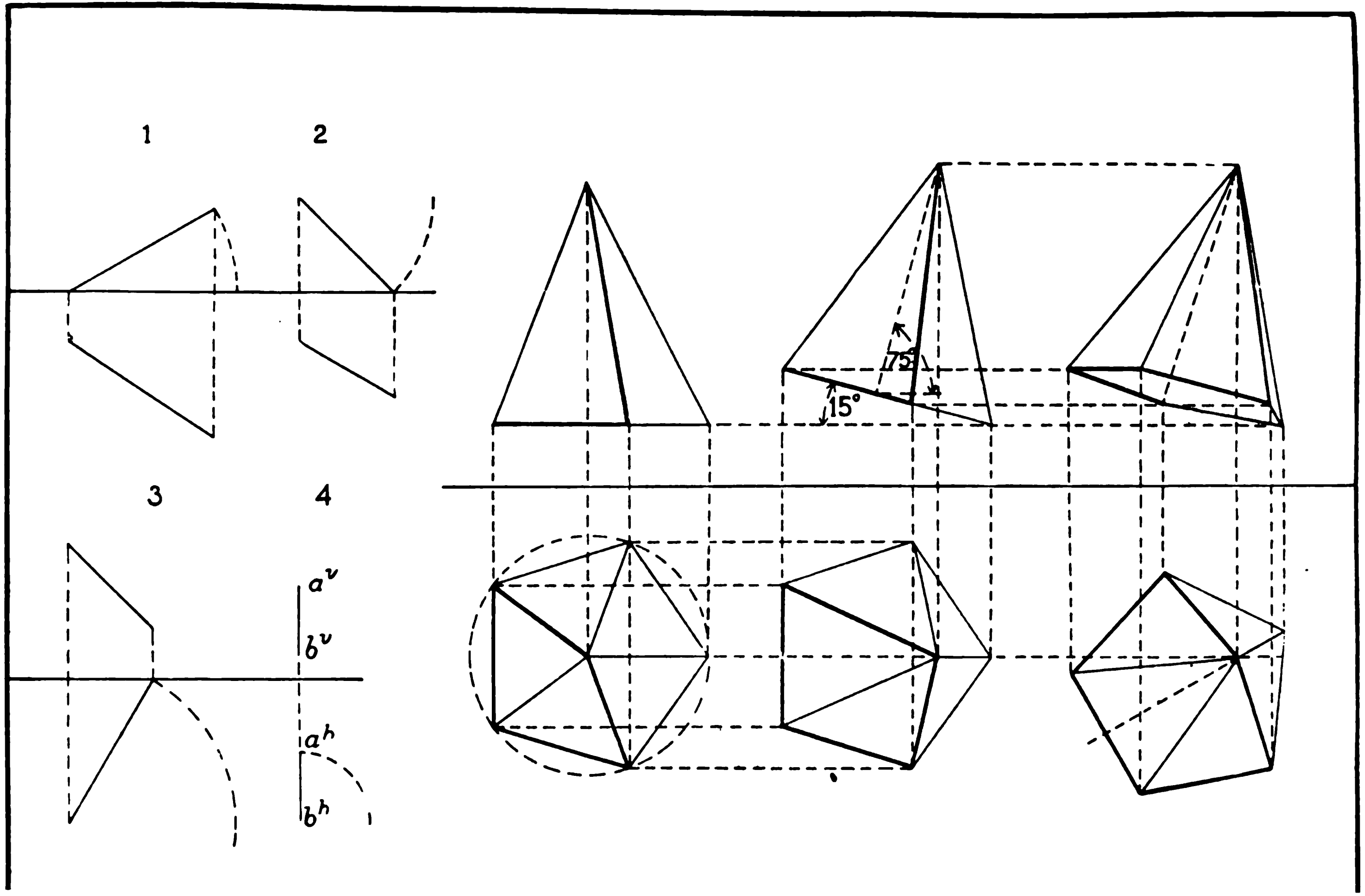
In Figs. 3 and 4, the true lengths are to be found by completing the revolutions indicated. The left-hand end of Fig. 3 is ¾ inch from the margin, 1½ inches from V, and 1⅝ inches above H. The horizontal projection makes an angle of 60° and extends to the ground line, and the vertical projection is inclined at 45°.

The fourth figure is 3 inches from the border, and represents a line in a profile plane connecting points *a* and *b*. *a* is 1¼ inches above H and ¾ inch from V; and *b* is ¼ inch above H and 1½ inches from V.

The figures for the middle ground line represent a pentagonal pyramid in three positions. The first position is the pyramid with the axis vertical, and the base ⅝ inch above the horizontal. The height of the pyramid is 2½ inches, and the diameter of the circle circumscribed about the base is 2½ inches. The center of the circle is 6 inches from the left margin and 1¾ inches from V. Spaces between figures to be ¾ inch.

In the second figure the pyramid has been revolved about the right-hand corner of the base as an axis, through an angle of 15°. The axis of the pyramid, shown dotted, is therefore at 75°. The method of obtaining 75° and 15° with the triangles was shown in

PLATE XV



Part I. From the way in which the pyramid has been revolved, all angles with V must remain the same as in the first position: hence the vertical projection will be the same shape and size as before. All points of the pyramid remain the same distance from V. The points on the plan are found on T-square lines through the corners of the first plan and directly beneath the points in elevation. In the third position the pyramid has been swung around, about a vertical line through the apex as axis, through 30°. The angle with the horizontal plane remains the same; consequently the plan is the same size and shape as in the second position, but at a different angle with the ground line. Heights of all points of the pyramid have not changed this time, and hence are projected across from the second elevation. Shade lines are to be put on between the light and dark surfaces as determined by the 45° triangle.

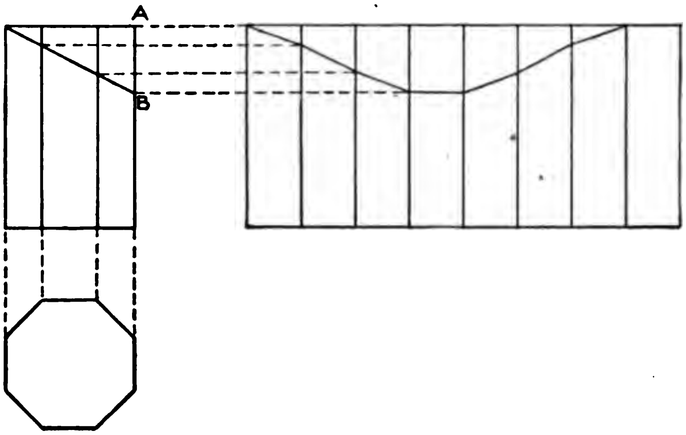


Fig. 96.

PLATE XII.

Developments.

On this plate draw the developments of a truncated octagonal prism, and of a truncated pyramid having a square base. The arrangement on the plate is left to the student; but we should suggest that the truncated prism and its development be placed at the left, and that the development of the truncated pyramid be placed under the development of the prism; the truncated pyramid may be placed at the right.

The prism and its development are shown in Fig. 96. The prism is 3 inches high, and the base is inscribed in a circle 2⅛ inches in diameter. The plane forming the truncated prism is passed as indicated, the distance A B being 1 inch. Ink a sufficient number of construction lines to show clearly the method of finding the development.

The pyramid and its development are shown in Fig. 97. Each side of the square base is 2 inches, and the altitude is 3⅛ inches.

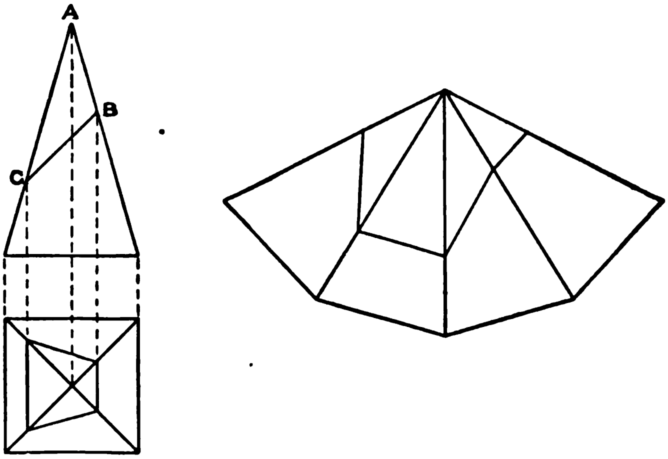


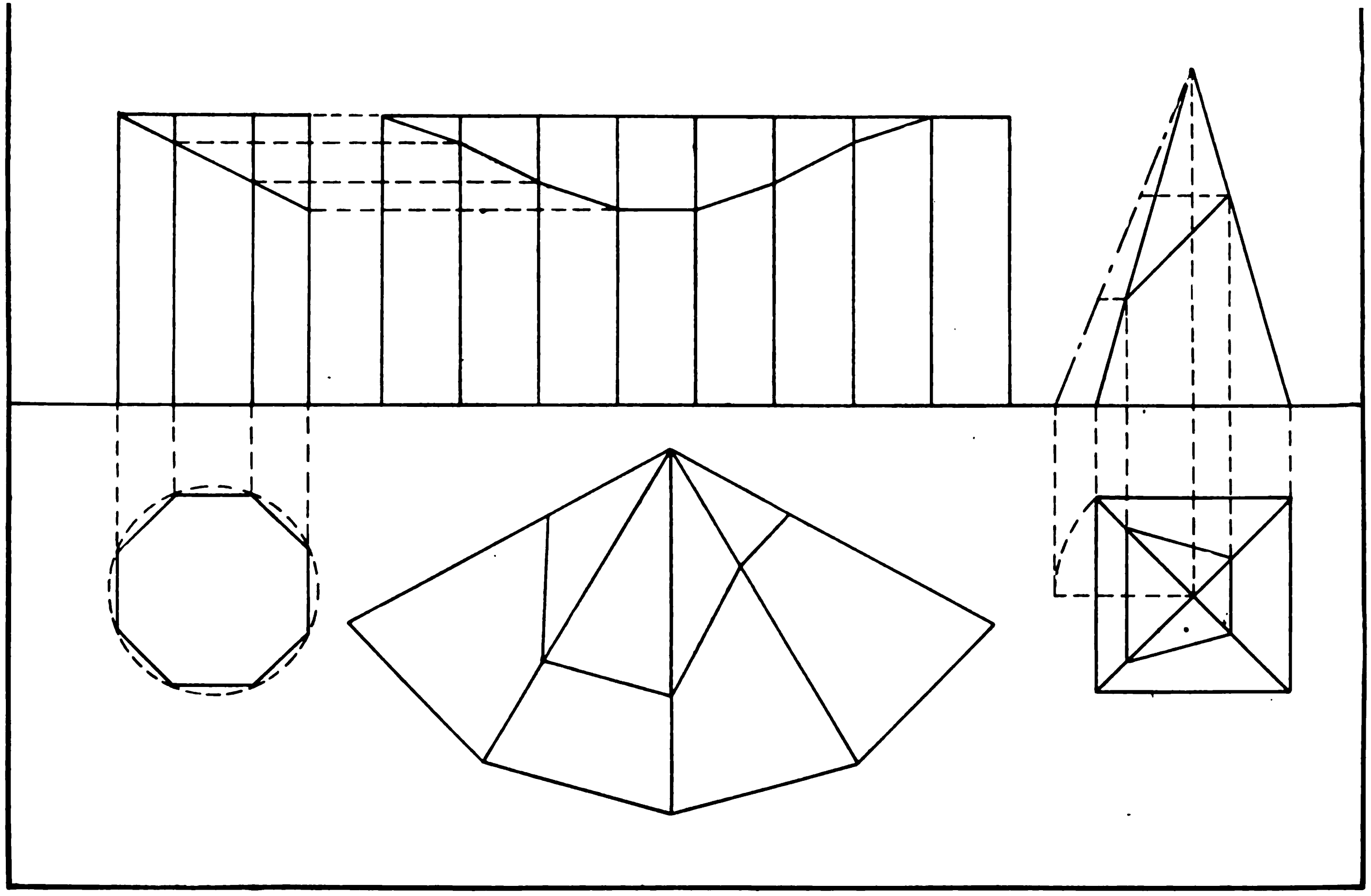
Fig. 97.

The plane forming the truncated pyramid is passed in such a position that A B equals 1⅜ inches, and A C equals 2⅛ inches. In this figure the development may be drawn in any convenient position, but in the case of the prism it is better to draw the development as shown. Indicate clearly the construction by inking the construction lines.

PLATE XIII.

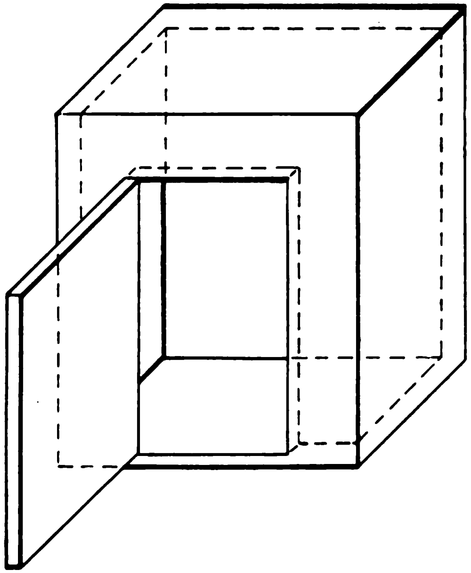
Isometric and Oblique Projection.

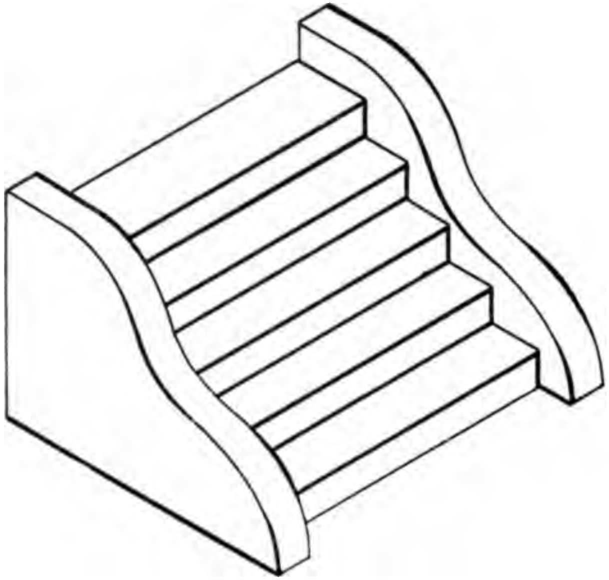
Draw the oblique projection of a portable closet. The angle to be used is 45°. Make the height 3⅛ inches, the depth 1⅛ inches, and the width 3 inches. See Fig. 98. The width of the closet



MARCH 7, 1907 HERBERT CHANDLER CHICAGO, ILL.

PLATE XIII





MARCH 14, 1907 HERBERT CHANDLER CHICAGO, ILL.

is to be shown as the left-hand face. The front left-hand lower corner is to be 1 inch from the left-hand border line and 2 inches from the lower border line. The door to be placed in the closet should be 1⅝ inches wide and 2¾ inches high. Place the door centrally in the front of the closet, the bottom edge at the height of the floor of the closet, the hinges of the door to be placed on the left-hand side. In the oblique drawing, show the door opened at an angle of 90 degrees. The thickness of the material of the closet, door, and floor is ⅛ inch. The door should be hung so that when closed it will be flush with the front of the closet.

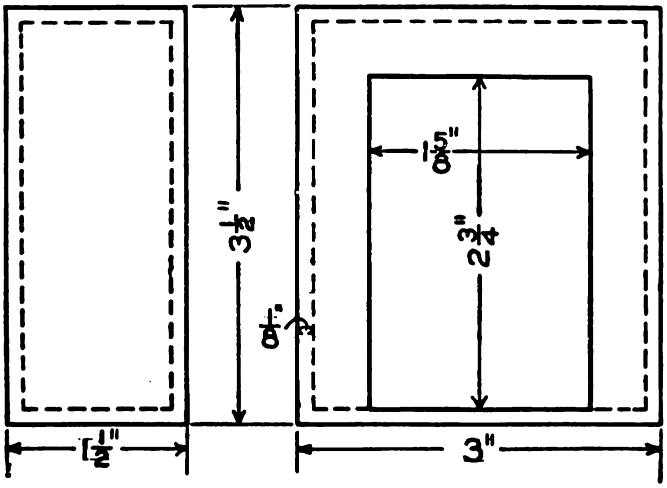


Fig. 98.

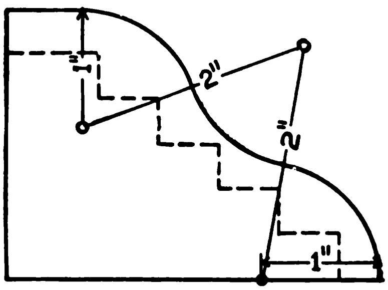


Fig. 99.

Make the isometric drawing of the flight of steps and end walls as shown by the end view in Fig. 99. The lower right-hand corner is to be located 2¼ inches from the lower, and 5 inches from the right-hand, margin. The base of the end wall is 3⅛ inches long, and the height is 2¼ inches. Beginning from the back of the wall, the top is horizontal for ⅝ inch, the remainder of the outline being composed of arcs of circles whose radii and centers are given in the figure. The thickness of the end wall is $\frac{3}{8}$ inch, and both ends are alike. There are to be five steps; each rise is to be $\frac{3}{8}$ inch, and each tread $\frac{1}{2}$ inch, except that of the top step, which is $\frac{3}{4}$ inch. The first step is located $\frac{3}{8}$ inch back from the corner of the wall. The end view of the wall should be constructed on a separate sheet of paper, from the dimensions given, the points on the curve being located by horizontal co-ordinates from the vertical edge of the wall, and then these co-ordinates transferred to the isometric drawing. After the isometric of one curved edge has been made, the others can be readily found from this. The width of the steps inside the walls is 3 inches.

PLATE XIV.

Free-hand Lettering.

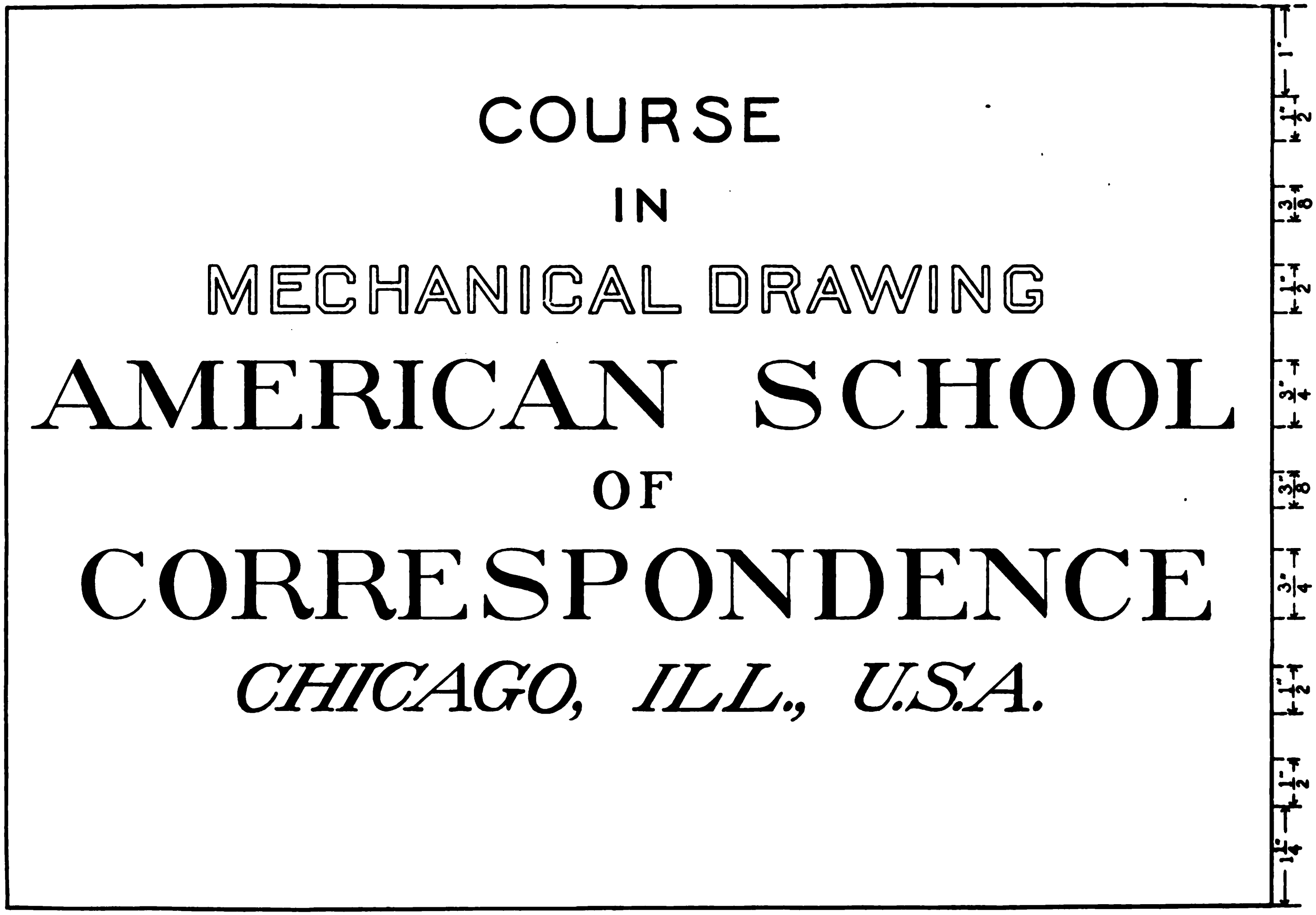
On account of the importance of free-hand lettering, the student should practice it at every opportunity. For additional practice, and to show the improvement made since completing Part I, lay out Plate XIV in the same manner as Plate I, and letter all four rectangles. Use the same letters and words as in the lower light-hand rectangle of Plate I.

PLATE XV.

Lettering.

First lay out Plate XV in the same manner as previous plates. After drawing the vertical center line, draw light pencil lines as guide lines for the letters. The height of each line of letters is shown on the reproduced plate. The distance between the letters should be $\frac{1}{2}$ inch in every case. The spacing of the letters is left to the student. He may facilitate his work by lettering the words on a separate piece of paper, and finding the center by measurement or by doubling the paper into two equal parts. The styles of letters shown on the reproduced plate should be used

PLATE · XV



COURSE

IN

MECHANICAL DRAWING

AMERICAN SCHOOL

OF

CORRESPONDENCE

CHICAGO, ILL., U.S.A.

APRIL 24, 1907 HERBERT CHANDLER CHICAGO, ILL

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

PLANE SURVEYING

PART I

1. Explain by a diagram how to erect (with the tape alone) a line at right angles to a given line.

2. The sides of a triangular field are 826,432 and 529 feet. Find the area of the field in acres, rods and square rods.

3. Find the area of a triangle whose sides are 31, 40 and 55 rods.

4. Given in Fig. 14, C B = 2.85 chains, C D = 3.67 chains, C S = C L = 0.52 chains and L S = 0.75 chains. Calculate the area of the triangle B C D.

5. A certain line is known to be 530 feet in length, but when measured with a certain tape is found to be $533\frac{1}{2}$ feet in length. Determine the true length of the tape.

6. A certain field is measured with a Gunter's chain and is found to contain 5.75 acres. It is afterwards discovered that the chain is $\frac{3}{10}$ of a foot too long. Find the true area of the field.

7. If a line as measured is found to be $432\frac{3}{4}$ feet in length and it is afterwards discovered that the tape is too short by $\frac{1}{8}$ of a foot, what is the true length of the line?

8. A level bubble has a radius of 150 feet and its scale has 10 spaces in an inch. What error in leveling will result at a distance of 275 feet when the level bubble is $1\frac{1}{2}$ spaces out of level?

9. At a distance of 150 feet, two rod readings were 3.704 and 3.745 and the bubble moved over $\frac{1}{8}$ inch. Determine the radius of the bubble tube.

10. What error in leveling will result at a distance of 123 feet if the bubble is $2\frac{3}{4}$ spaces out of level, the scale of which has 7 spaces in an inch, the radius being 176 feet?

11. If the difference of rod readings is 0.03 foot and the bubble having a radius of 50 feet moves over 0.015 foot. determine the distance from the instrument to the rod.

12. Given the distances measured along the straight line A B in Fig. A. Page 22, to be 35, 40, 55, 45, 50, 70, 30, 45 and 25 feet. The offsets beginning with 0 at A are 40, 35, 0, -55, -65, -30, 0, 25 and 0 feet at B. Determine the area included between the line A B and the broken line A C D E F B.

13. An angle is 5 degrees and 1 minute and the distance 823 feet. What is the length of the subtended arc?

14. In your own words, describe the Gunter's chain, and its advantages in land surveying. Describe the engineer's chain and state what errors are liable to occur in using either chain for measuring lines.

15. In your own words, describe the different kinds of tapes and explain fully the advantages of the band tape over the chain for measuring the lengths of lines.

16. In your own words, describe the wye level, accompanying the description with sketches whenever necessary.

17. Define the following terms: Line of collimation; instrumental parallax; spherical aberration; chromatic aberration.

18. In your own words, state the adjustments of the wye level *in their order*.

19. In your own words, describe how to make the tests for the several adjustments of the wye level.

20. In your own words, describe with sketches, how to make several adjustments of the wye level, *in their order*.

21. Define the following terms: Back-sight; fore-sight; height of instrument; datum plain; bench-mark; peg; elevation.

22. In your own words, describe how to "set" the wye level and the field operations of leveling.

23. Assuming your own rod readings, prepare a system of level notes; calculating heights of instrument and elevations.

24. In your own words, describe the Dumpy level and explain how it differs from the wye level.

25. State and explain fully the adjustments of the Dumpy level *in their order*.

REVIEW QUESTIONS

ON THE SUBJECT OF

PLANE SURVEYING

PART II

---

1. Give a detailed description of the transit.

2. Give the *reasons* for each of the adjustments of the transit. Draw a diagram in each case.

3. Describe fully *in their order* how to test the adjustments of the transit.

4. Describe fully in their order how to make the several adjustments of the transit.

5. Define the following: Latitude of a station; longitude of a line; double longitude; departure.

6. Explain the use of double longitudes. Draw a figure, and explain how latitudes and departures may be gotten from the length and bearing of a line.

7. In order to find the difference in height of two peaks M and N, a base line $A\,B$ was laid off 5,000 feet long; and the horizontal angles $BAM = 120° 30'$, $BAN = 49° 15'$, $ABM = 40° 35'$, and $ABN = 95° 07'$, were read. At A, the angle of elevation of M was $17° 19'$, and the angle of elevation of N was $18° 45'$. Compute the difference in the height of the two peaks.

Ans. M is 226.59 feet above N.

8. Draw a figure, and deduce a general rule for the double longitude of any course in terms of the double longitude and departure of the preceding course.

9. Explain what is meant by balancing a survey.

10. Describe fully how the latitudes and departures of a series of courses may be balanced, and how to determine the balanced length and bearing of each course.

11. Let $c + f = 0.87$ feet, $s' = 4.65$ feet, and $I = 3° 32'$. Compute the horizontal distance to the rod and the difference in elevation. What error results when $c + f$ is neglected?

12. In order to find the direction and distance between two points R and Q, the following lines are run. RA, S 87° 37′ W. 930.57 feet; AB, W 621.03 feet; BQ, S 88° 15′ West, 82.78 feet. Compute the bearing and length of RQ, and locate the point where it crosses AB, with reference to A.

13. In order to find the direction and distance of a point, the following lines are run: AC N 42° 15′ E 714.5 feet. CB N 1° 8′ E 210.5 feet. Compute the distance and bearing of the two points. Draw a diagram before starting the solution.

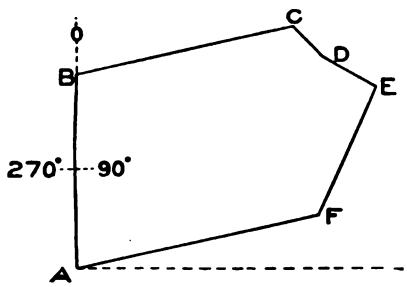


Fig. A.

14. Draw a diagram similar to the hands of a clock, and explain what is meant by an azimuth.

15. If the limb of a transit is divided into 20 minute spaces, show how the vernier must be made in order to read 1 minute; also how to read 20 seconds. Give diagrams of these verniers.

16. Explain the relation between azimuth and bearings of lines in the four quadrants. Determine the azimuths of the courses in Problem 3, page 88.

17. Compute the area of Fig. A, taking the azimuth of BC as 0° 00′. Also taking the azimuth of AB as 90° 00′.

AB = 800 feet.	A = 58° 14′
BC = 500 feet.	B = 120° 00′
CD = 200 feet.	C = 125° 00′
DE = 100 feet.	D = 200° 00′
EF = 600 feet.	E = 83° 34′
FA = 700 feet.	F = 133° 12′

ANS. Area = 11 acres 1 rood 1.62 rods.

18. Describe fully the various steps involved in determining the area of an enclosed field from latitudes and departures, and state the rule for calculating the area.

19. A polygon of six sides has the following interior angles:

$A = 58° 24'; B = 121° 30'; C = 127° 45'; E = 95° 19'; F = 133° 2'$. The azimuth AB is 00° 0′. Find the azimuth of each of the other sides.

20. Give a complete description of the surveyor's compass. Explain fully how to use the compass in the field in determining areas.

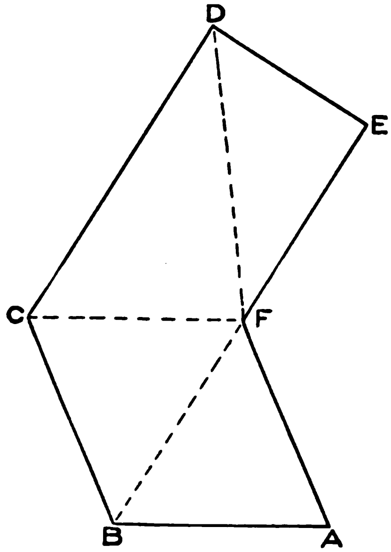


Fig. B.

21. Given the latitude of one end of a line as + 2,804.4, its longitude as + 4,661.3, its length as 797.2 feet, and its azimuth as 115° 44′ 28″. Compute the latitude and longitude of the other end. Draw a figure before starting the solution.

Ans. Latitude = 2,458.2 feet.
Longitude = 5,379.4 feet.

22. Describe fully the field work of running a traverse.

23. Explain fully the field work of laying out angles.

24. In Problem 2, Page 88, the bearing of the first course is changed to S. 15° E. Calculate the changed bearings of the other courses.

25. Describe fully how to test and make the adjustments of the compass in their order.

26. Explain fully how to lay out a true meridian from Polaris.

27. Explain the application of, and describe fully how to carry out, the "peg" adjustment for the transit.

28. Define and fully explain the terms: Daily, Annual, and Secular Variation.

29. Describe the stadia and deduce the formulæ for its use.

30. How many feet are represented by one inch on a scale of $\frac{1}{1000}$? How many acres are represented by one square inch on

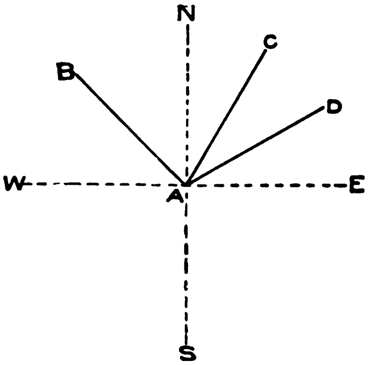


Fig. C.

a scale of $\frac{1}{50000}$?

Ans. $\begin{cases} 83\frac{1}{3} \text{ feet.} \\ 398.6 \text{ acres.} \end{cases}$

31. Compute the area of Fig. B, which represents a recent survey of a farm, from the following data:

A B = 317.8 feet;
B F = 284.3 feet;
F A = 250.5 feet;
F C = 512.7 feet;
F D = 510.0 feet;
D E F = 90° 00′;
E F D = 69° 45′;
D F C = 61° 12′;
C F B = 49° 30′;

Ans. Area = 5 acres 103 rods 81 sq. feet.

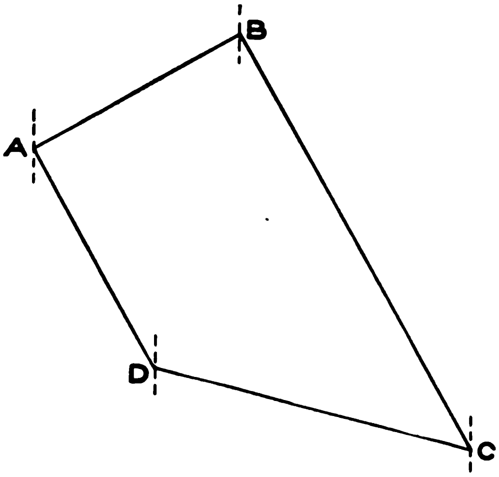


Fig. D.

32. Describe fully the field work of carrying out a stadia survey over uneven ground.

33. A triangle $A\,B\,C$ has sides with the following lengths and azimuths:

$A\,B$, l = 312 feet; Z = 45 degrees.
$B\,C$, l = 540.4 feet; Z = 135 degrees.
$C\,A$, l = 624.0 feet; Z = 285 degrees.

Compute the latitude differences and longitude differences and the double longitudes for each course.

34. The bearing of $A\,C$ (Fig. C) is N 8½° E, that of $A\,D$ is N 46° E. Find the value of the angles $C\,A\,D$ and $D\,A\,E$.

35. Find the angle $A\,B\,C$ (Fig. D) when the bearing of $A\,B$ is 42° E, and that of $B\,C$ is S 29¼° E. What will $B\,A$ be when the first bearing is reversed?

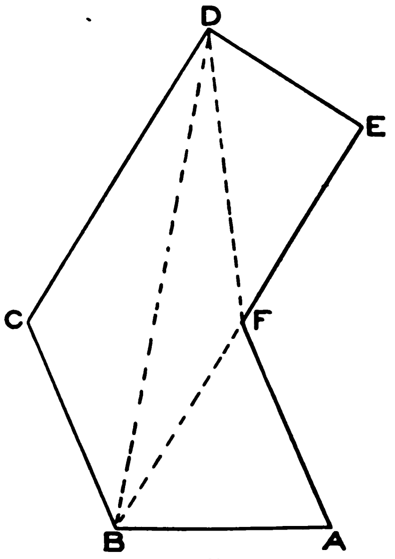


Fig. E.

REVIEW QUESTIONS

ON THE SUBJECT OF

PLANE SURVEYING

PART III

---

1. Let it be required to prepare a table of declinations for July 16, 1904, for a point whose latitude is 38° 30′, and which lies in the "Eastern Time" belt. The sun's apparent declination at Greenwich Mean Noon for that date is 21° 24.3′ and the hourly change is − 24″ .38.

2. The lengths and bearings of the sides of a field are as follows:

Station.	Distance.	Bearings.
1	12.41	S 21° W
2		N 83¼° E
3	8.25	
4	4.24	N 47° W

It is required to find the length of Course 2 and the bearing of Course 3.

3. In your own words explain fully the various methods of surveying areas by the plane-table. Prepare a sketch for each case.

4. Explain the term "adjusting the triangle" and why adjustment is necessary.

5. A certain grade line has a fall of 12.5 feet in one-half of a mile. Determine the percentage of grade and the vertical angle corresponding to it.

6. In Fig. 103 given BC = 385 feet; ABC = 70° 05′; ACB = 63° 28′. Calculate the length of BD and the length of AD, and plot the figure accurately.

7. It is required to determine the linear convergence for a township situated in latitude 43° 18′ north.

8. In your own words describe fully the adjustments of the plane-table in their order.

9. Explain under what circumstances the transit and stadia may be used and when the plane-table may be used. Enumerate the advantages and disadvantages of each instrument.

10. In Fig. 95 the scale reading was 3½ and the reading of the head 26. Determine the grade of the line AB.

11. In Fig. 101 given HE = 265 feet; AHE = 112° 30′; BHE = 35° 10′; BEH = 116°; BEA = 85°. It is required to plot the figure accurately and to find the angle AHD, the length of HD, and the length of AD.

12. Explain in your own language the methods of using a steel tape in the measurement of a base.

13. The lengths and bearings of the sides of a field are as follows:

Stations.	Distances.	Bearings.
1	10.63	N 52° E
2	4.10	S 29½° E
3	7.69	S 31½° W
4		

It is required to find the length and bearing of Course 4.

14. In the measurement of a base line, the tape is divided into eight sections of 50 feet each. The weight per foot of tape is .0145 lbs. The tension applied to the end of the tape is 15 lbs. Determine the amount of shortening of each tape length. If there are 75 full tape lengths in measured base line, determine the total corrections for sag.

15. Explain fully in your own words the nature of Topographical Surveying and what instruments are particularly adapted to this work.

16. A line is to be run at a grade of 4.75 per cent. Explain fully how this would be done with the gradienter.

17. In Fig. 111 given BE′ = 375 feet; angle CBE′ = 112° 25′; angle CE′B = 52° 16′. Plot the figure accurately to a scale of 100 feet to the inch. Calculate the length of BC and if stake B is numbered 180 + 36, determine the number of stake C.

18. In your own words describe the plane-table and its uses; its advantages and disadvantages.

19. Explain fully the organization of a topographic party using the transit and stadia, and explain the method of keeping the field-notes.

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